Prepared by ESA
CGMS Plenary Information Document

STATUS OF THE CURRENT AND FUTURE ESA EARTH OBSERVATION MISSIONS AND PROGRAMMES

CGMS is informed of the current status of the European Space Agency Earth Observation missions currently in-orbit. Two of them, MSG and MetOp are in co-operation with EUMETSAT.

Copernicus represents the major continuing initiative of European efforts in Earth Observation. The first Copernicus dedicated satellite ("Sentinel-1A") was launched on 3 April 2014, followed by Sentinel-2A in June 2015, Sentinel-3A in February 2016, Sentinel-1B in April 2016,Sentinel-2B in April 2017, Sentinel-5P satellite in October 2017, Sentinel-3B in April 2018 and Sentinel-6 Michael Freilich on 21 November 2020; other Sentinels will follow in the coming years. Sentinel missions are developed, launched and operated in partnership with the European Union and EUMETSAT. The Sentinel-4 and 5 instruments developed by ESA will fly respectively on the MTG-S and Metop-SG missions also developed by ESA in cooperation with EUMETSAT.

The Earth Explorer missions currently in orbit (SMOS, CryoSat, Swarm, Aeolus) are all performing extremely well and the related data exploitation is based on continuous data of excellent quality. The three missions all feature strong elements of international collaboration and a growing synergy between them. The SMOS satellite was launched on 2 November 2009. The CryoSat-2 satellite was launched on 8 April 2010, the Swarm satellites on 22 November 2013. Aeolus is the last Earth Explorer satellite put into orbit on 21 August 2018 and its Doppler Wind Lidar technique used for measuring wind profiles from space has already been fully demonstrated. The positive impact of Aeolus on the weather forecast has been also seen by multiple Numerical Weather Prediction centres world-wide, in particular by ECMWF.

The Proba-V small satellite was launched on 7 May 2013. Its coarse resolution imager has, together with Sentinel-3, continued the data acquisition of the Vegetation payload on-board SPOT-4 and 5, during the reporting period. However from July 2020, owing to its orbital drift, Proba-V is no longer considered as a mission fulfilling an operational role, and will instead be dedicated to experimental activities with a reduced data acquisition scheme.

CGMS is further informed of the current status of the **future** European Space Agency Earth Observation missions. Two of them, MTG and MetOp-SG, are in co-operation with EUMETSAT. The Living Planet Programme has three lines of implementation: Earth Explorer satellites, Earth Watch satellites plus services and applications demonstration.

Progress in the preparation of the forthcoming Explorer missions, EarthCARE, Biomass, FLEX, and FORUM is described. FORUM was selected for implementation as Earth Explorer 9 (EE-9) on 23-25 September 2019. The phase A/B1 for FORUM is close to completion and the bidding period for the FORUM Space Segment ITT for the phases B2, C/D and E1 has been extended to 18 May 2021.

The Phase A system studies are ongoing for the Earth Explorer 10 (EE-10) candidate mission, Harmony, with two parallel system studies.

On 25 May 2020, ESA issued a Call for Ideas for Earth Explorer 11 (EE-11). Fifteen (15) proposals have been submitted on 4 December 2020 and are under evaluation. Earth Explorer 11 is foreseen to be launched in the 2031–2032 timeframe. The decision on the mission ideas proceeding to phase 0 will be taken PB-EO at its meeting on 10 June 2021.

Following the decisions taken at Space19+ (ESA's Council at Ministerial Level), new activities related to Aeolus Follow-On, Arctic Weather Satellite (AWS), TRUTHS and ALTIUS are ongoing. Each of these missions are planned contribute routine, operational monitoring data to improve our understanding of the Earth system and climate change.

Looking to the future, the six Copernicus Expansion missions are currently in phase B2/C/D/E1, addressing EU policy and gaps in Copernicus user needs, and each expanding the current capabilities of the Copernicus space component: CHIME, CIMR, CO2M, CRISTAL, LSTM, and ROSE-L.

CGMS is also informed of the status of the Earth Watch Programme element, Global Monitoring of Essential Climate Variables (also known as the ‘ESA Climate Change Initiative’ or CCI). The CCI has continued to progress very well since its inception in 2008. In 2016, a second phase of the programme, CCI+, was approved by ESA member states which is allowing to study and monitor 23 essential climate variables (ECV) derived from satellite data, fulfilling GCOS objectives. Out of these 23 ECVs, 16 have been handed over to the Copernicus Climate Change Service (C3S) for operational use.

As a general observation, the COVID-19 pandemic has affected several activities related to the procurement of satellites and instruments at different degrees. Thanks to appropriate measures, the impacts on development projects have been mitigated has much as possible, while overall, the operations of ESA satellites currently in orbit and services to users have been kept nominal.

Contents

STATUS OF THE CURRENT AND FUTURE ESA EARTH OBSERVATION MISSIONS AND PROGRAMMES

1 INTRODUCTION

This paper provides information on the status of the current and future European Space Agency Earth Observation missions. ESA's EO Programme comprises a science and research element, which includes the Earth Explorer missions, and an Earth Watch element, which is designed to facilitate the delivery of Earth observation data for use in operational services. Earth Watch includes the well-established meteorological missions developed in coordination with the European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT). These missions (MSG, MTG, MetOp and MetOp-SG) are not dealt with in this report.

Current in-flight missions include four R&D satellites missions (6 satellites) from the Earth Explorer series, two small satellites of the Proba series, and eight Sentinel satellites. The status of future Earth Explorer and Earth Watch missions is presented, as well as the progress in the development of the ESA Climate Change Initiative (CCI).

Although the past ESA ERS-1, ERS-2, Envisat and GOCE missions are no longer operating, thousands of users still access the large ESA on-line archives to get products generated from their respective instrument complements.

2 CURRENT ESA SATELLITE SYSTEMS

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
PROBA-1	7:30 (D) 615 km	22/10/2001	Earthnet on line	CHRIS, SREM	The orbit is drifting from the original 10:30 desc. ECT.
SMOS (with CNES and CDTI)	06:00 (A) 755 km	2/11/2009	SMOS data centres	MIRAS (Microwave Imaging Radiometer using Aperture Synthesis), GPS, STA	L-band radiometer for salinity & soil moisture observation
PROBA-2	06:00 (A) 730 km	2/11/2009	Earthnet on line	SWAP, LYRA, TPMU, DSLP	2nd flight unit of the PROBA programme. Main mission: space weather
CryoSat-2	717 km (92° incl.)	8/04/2010	Earthnet on line	SIRAL (SAR Interferometric Radar Altimeter), DORIS, LRR	Polar ice monitoring
PROBA-V	10:30 (D) 820 km	5/07/2013	Earthnet on line	VEGETATION-P	2nd flight unit of the PROBA programme. Main mission: vegetation monitoring
Swarm A & C (with CNES and CSA)	87.35° 460 km	22/11/2013	Earthnet on line	ACC, SM, EFI (SWARM), GPS (ESA), LRR (DLR), STR (SWARM), VFM	Earth magnetic field

Satellites	Equator Crossing Time Altitude	Launch date	Access to data or products	Instruments	Status, applications and other information
Swarm B	87.75° 530 km	22/11/2013	Earthnet on line		
Aeolus	97° 320 km	22/08/2018	Earthnet on line	ALADIN instrument (Atmospheric Laser Doppler Instrument)	Global observations of wind profiles from space to improve the quality of weather forecasts, and to advance our understanding of atmospheric dynamics and climate processes.
Sentinel-1A (with EC)	06:00 (D) 693 km	03/04/2014	Copernicus Space component data access	SAR-C	Radar imagery
Sentinel-2A (with EC)	10:30 (D) 786 km	22/06/2015	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	MSI (Multispectral imager)	Land and vegetation observation
Sentinel-3A (with EC)	10:00 (D) 814.5 km	16/02/2016	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	DORIS, GPS, LRR, MWR, OLCI, SLSTR, SRAL	Primary mission: ocean observation. Secondary mission: atmosphere and land applications
Sentinel-1B (with EC)	06:00 (D) 693 km	25/04/2016	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	SAR-C	Radar imagery
Sentinel-2B (with EC)	10:30 (D) 786 km	06/03/2017	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	MSI (Multispectral imager)	Land and vegetation observation
Sentinel-5P (with EC and NSO)	13:30 (D) 824 km	13/10/2017	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	TROPOMI	Atmospheric composition and air quality monitoring.
Sentinel-3B (with EC)	10:00 (D) 814.5 km	25/04/2018	Data available from centres of the Payload Data Ground Segment (PDGS). Real-time availability possible at appointed X-band stations.	DORIS, GPS, LRR, MWR, OLCI, SLSTR, SRAL	Primary mission: ocean observation. Secondary mission: atmosphere and land applications
Sentinel-6 Michael freilich	non-Sun-synchronous orbit 1336 km	21 November 2020	Products are still not accessible to public during the ongoing commissioning phase	AMR-C, DORIS-NG, GNSS POD Receiver, GNSS-RO Receiver, LRA (Sentinel-6), Poseidon-4 Altimeter	Provides continuity of the reference, high-precision ocean topography service after Jason-3

3 STATUS OF CURRENT EARTH EXPLORER SATELLITES

Three ESA Earth Explorer missions are currently in operation, namely SMOS (launched in 2009), CryoSat-2 (launched in 2010) and the Swarm constellation of 3 satellites (launched in 2013). All three missions, as well as GOCE, have provided outstanding results of interest to the meteorological and climate research communities at large.

3.1 GOCE

In orbit from March 2009 to November 2013, the Gravity field and steady-state Ocean Explorer (GOCE) measured the Earth's gravity field with unprecedented detail to advance our understanding of ocean circulation, sea-level change and Earth-interior processes.

3.1.1 Status of spacecraft

GOCE successfully completed its last measurement cycle at an altitude of 223.88 km on 19 October 2013. The satellite re-entered into the Earth atmosphere on 11 November 2013. No damage or casualties due to debris have been reported. The GOCE spacecraft was indeed working very well until just minutes before re-entry.

3.1.2 Performance and results

All Level 1 and Level 2 data up to 1st October 2013, which marks the last instrument calibration activity, have been processed and released to the user community.

The GOCE Level-1b and Level-2 reprocessing campaigns and the related delivery of the Release 6 gravity field products have been completed and the complete set of data released to the user community together with the satellite house-keeping database. The data have been migrated to the new user data access system and rendered accessible at the end of February 2020. The previous user data access system will be available until end of March 2020. The GOCE Gravity Field Model coefficients have been released in the common ICGEM format together with the associated variance-covariance matrices.

The final version of the GOCE User Toolbox (GUT) software package (v3.2) including both the GUI and the updated toolbox documentation and data package has been validated and accepted by ESA. Release to users is planned for Q2 2020.

Programmatic discussions have also been held in March 2020 between ESA and NASA, based on a series of meetings and teleconferences in 2019, to identify the most suitable scenario for implementation of a joint mass change mission based on a joint constellation of 2 pairs of satellites in an optimum orbit configuration, leveraging on technology developments, and technical and scientific expertise available both in Europe and in the US. The proposed mission architecture responds to user requirements previously established by the Interagency Gravity Science Working Group and builds upon the heritage from CHAMP, GOCE, GRACE, GRACE-FO and on-going pre-developments on laser–ranging interferometry in preparation for the Next Generation Gravity Mission (NGGM), the LISA mission, and in the US Decadal Survey Mass Change Designated Observable (MCDO) study activity.

3.2 SMOS

Launched on 2 November 2009, SMOS is the second Earth Explorer Opportunity mission to be developed as part of ESA's Living Planet Programme. SMOS carries a novel microwave sensor to capture images of brightness temperature, from which information on soil moisture and ocean salinity is derived. The data acquired from the SMOS mission leads to better weather and extreme-event forecasting, and contribute to seasonal-climate forecasting.

3.2.1 Status of spacecraft

The platform is operated under CNES responsibility. No major anomalies or failures have been identified since launch, and the same applies for the interfaces to the payload. Collision Avoidance Manoeuvres (CAM) are performed when necessary as well as Orbit Correction Manoeuvres (OCM) to maintain the mission performances.

3.2.2 Performance and results

The SMOS payload is operating nominally, with the exception of some anomalies having a minor impact on data availability. In total, the anomalies caused 2h 2min 22s of on-board data loss (0.094%) and 3h 5min 24s of on-board degraded data (0.143%) from 1 January 2021 to 31 March 2021, with an overall mission performance of 99.76%, which is within the system performance requirement of 98% for generating observation data. The cumulative data lost since 1 May 2010 amounts to 0.085% and the degraded data amounts to 0.471%, with an overall mission performance of 99.44%.

The data acquisition is split between the XBAS acquisition system at ESAC and Svalbard (operated by KSAT). Globally, 99.74% of the dumped passes have been acquired with both stations. The acquired data were successfully processed to 99.96% for all product Levels including near-real time (NRT) for the period between 1 January and 21 March 2021. The timeline of 165 minutes for the NRT products was met in 95.99%.

Since the opening of the data access service (https://smos-diss.eo.esa.int), approximately 27 million products have been downloaded by more than 2200 active accounts (with about 35 new accesses per month), for a total volume of about 1000 TB (Figure 1). A monthly report on SMOS data performances is available to users on https://earth.esa.int/eogateway/instruments/miras

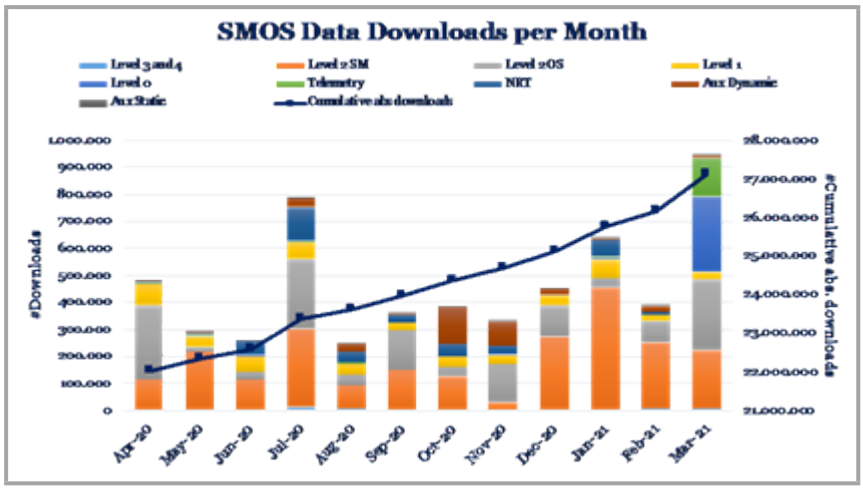

Figure 1: *Performance of ESA SMOS data portal, which is operational since March 2016.*

Around 27 million products have been downloaded by more than 2200 active accounts, for a total volume of 1000 TB.

In addition SMOS products are disseminated by following services: The SMOS NRT Level-2 Soil Moisture product based on a Neural Network approach is also available from EUMETSAT's EUMETCast system, and through the UK Met Office. SMOS Level- 3/4 products are available from the national data centres in France and Spain: CATDS: www.catds.fr/Products/Available-products-from-CPDC , BEC: http://bec.icm.csic.es/data/ . The sea ice thickness products are available at https://spaces.awi.de/display/CS2SMOS. In addition, the Copernicus CMEMS service has also updated the SMOS/Cryosat-2 Level 4 sea-ice thickness processor to the version v203 in their sea-ice thematic assembly centre ICE TAC. The Level-4 soil freeze/thaw product is systematically disseminated by the Finnish Meteorological Institute (FMI) at https://nsdc.fmi.fi/services/SMOSService/.

The Level 2 sea surface salinity and soil moisture full mission reprocessing, carried out at ESAC facilities, was completed beginning of March 2021. The plan is to disseminate the dataset to user in May 2021 after a detailed data check.

The Expert Support Laboratories (ESL) are progressing in the assessment of data quality. Preliminary results are shown in Figure 2 for sea surface salinity and in Figure 3 for soil moisture. A full validation report is under preparation.

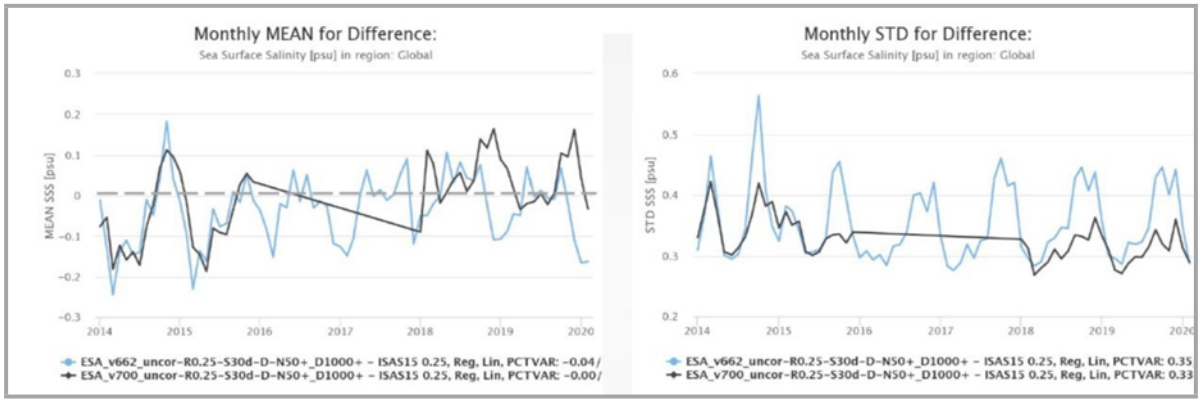

Figure 2: *Left panel: Monthly (L3) mean difference obtained from SMOS Level 2 sea surface salinity and Argo buoys over global ocean. Black line is for the SMOS reprocessed dataset v700, light blue line is for the current operational dataset (v662). Right panel: standard deviation of the difference.*

Statistics follow similar tendency, the reprocessed dataset (v700) shows a decrease in the monthly standard deviation of the difference. (Credits: LOCEAN).

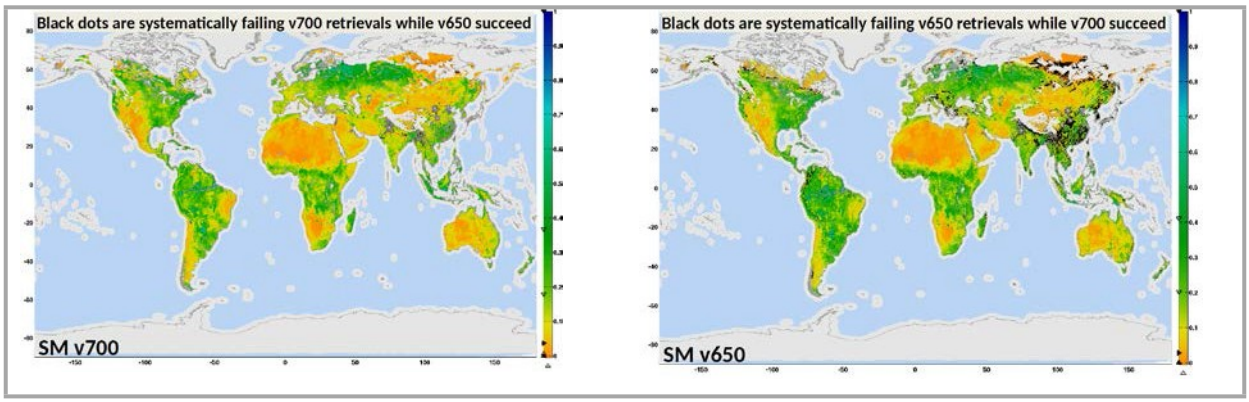

Figure 3: *Left: SMOS Level 2 soil moisture monthly map (May 2010) from V700 reprocessed dataset. Right: SMOS Level 2 soil moisture monthly map (May 2010) from V650 operational dataset. Scale unit is m3/m3. The retrieval performances for V700 are clearly increased in particular at interface with forest borders. (Credits: CESBIO)*

Copernicus Emergency Management Service: the European Flood Awareness System (EFAS), the European Forest Fire Information System (EFFIS), and the Copernicus Atmosphere Monitoring Service (CAMS) expressed an interest in using SMOS observations in their operational monitoring systems.

The Copernicus Climate Change Service (C3S) and the Copernicus Marine Environment Monitoring Service (CMEMS) use SMOS data sets as input for their services.

3.3 CryoSat-2

ESA's Earth Explorer CryoSat-2 mission, launched on 8 April 2010, is dedicated to the precise monitoring of the changes in the thickness of marine ice floating in the polar oceans and variations in the thickness of the vast ice sheets that overlie Greenland and Antarctica.

3.3.1 Status of spacecraft and mission

The **CryoSat** mission has reached **11 years of operations and exploitation** in early April 2020.

The overall performance of the CryoSat mission was in line with the previous reporting period. The performance of the mission (i.e. 98.68%) remains well above the design specifications. Since the start of the exploitation phase, the overall system availability is 99.17%.

There is enough fuel to operate the mission until end of 2024 (worst case scenario) but the intention is to switch to redundant branch at the end of spring 2023 to allow operations until the next extended phase (2025) and have remaining fuel to potentially support operations up to 2028+.

Besides, the latest forecast from Industry shows that battery would reach its critical capacity threshold in 2027. Beyond this point, the battery could still work but its linear fading rate is not guaranteed and the evolution of the battery capacity beyond that time is not known.

The current best estimation of the satellite life-time, based on fuel and battery is 2027.

The Mass Memory Formatting Unit (MMFU) experienced a software crash at the beginning of 2021, causing the loss of about 12 hours of housekeeping and science data. The MMFU was reconfigured back to nominal mode rapidly and no further crashes have occurred since then.

In addition, as a long standing issue, the unit continues to show occasional glitches when storing the data. The number of errors has decreased significantly as expected due to the seasonal MMFU temperature decrease. The impact remains minimal but often it required to manually re-create the packet stores causing loss of science data.

Therefore, it has been decided to switch-over to the backup unit (MMFU-B). Preparations are under way, including definition of new on-board control procedures to keep the prime MMFU (MMFU-A) as a backup and fully maintain the redundancy. The switch-over will take place mid-April 2021.

3.3.2 Performance and results

Overall, the ground segment performed nominally with no major issues.

The SIRAL instrument was programmed according to the current CryoSat Geographical Mode Mask 4.0.

During the reporting period, the end-to-end mission performance, namely the overall mission data return, which takes into account the planned (0.15%) and unplanned unavailability (0.44%) of the space and ground segments, was 99.41%.

Since the start of the mission, the overall availability of the science data has been 98.68% (see Figure 4), well above the design performance of 94.00%. The system availability, which considers only failures, is 99.17%.

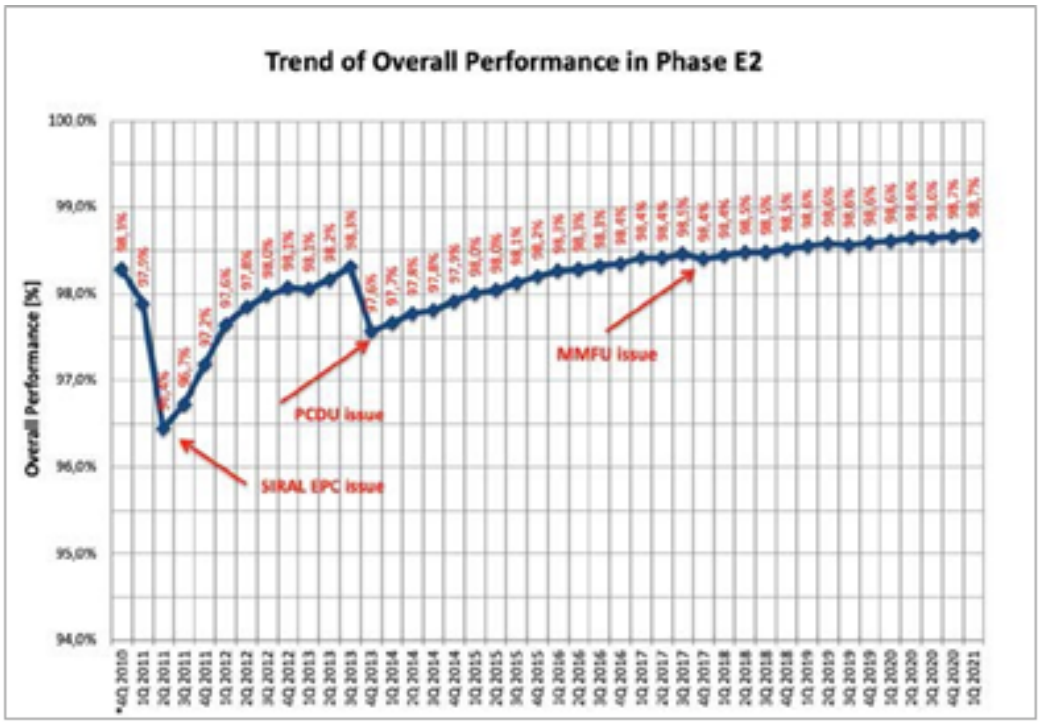

Figure 4: *Historical Mission Performance in Phase E2*

The CryoSat data availability page on the Earth web portal (https://earth.esa.int/web/guest/missions/cryosat/unavailability-periods) provides the list of all the mission data gap in downloadable format since the start of the mission, plus the details of the last six months.

Over the reporting period, an aggregate grand total in excess of 65 TB of products were downloaded from the Science Server.

On the new CryoSat Mission Earth Online (https://earth.esa.int/eogateway/missions/cryosat) website pages, users can find detailed information on how to access all CryoSat ice and ocean data (i.e. FBR, L1 and L2 type) including the Near Real Time products for Ice (NRT) and Ocean (NOP).

Users can access CryoSat products without prior registration but inherently acknowledging and accepting the EO Data Policy:

- Via FTP at ftp://science-pds.cryosat.esa.int
- Via HTTPS at https://science-pds.cryosat.esa.int/
- Through ESA EO-CAT on line main Catalogue at https://eocat.esa.int/sec/#data-services-area
- Through the dedicated website https://cryo2ice.org of the Cryo2Ice ESA-NASA dataset

Users can find also the 2-day, 14-day and 28-day sea ice thickness L3 product is available from the University College of London at http://www.cpom.ucl.ac.uk/csopr/seaice.html

The full reprocessed CryoSat Ice Baseline D data are now available on the Science Server (https://science-pds.cryosat.esa.int/) for download.

The systematic production of CryoSat ice and ocean data require accurate independent quality control that it is key to any new research paths in different Earth Science domains.

The overall daily quality and operational control of the ice and ocean CryoSat products are carried by IDEAS+ (UK). Reports are available on QC_Reports.

Detailed quality control of the L2 ice products is carried out by Mullard Space Science Laboratory (MSSL, UK). Reports are available on http://cryosat.mssl.ucl.ac.uk/qa/ .

Complementary quality control and science validation of the L2 CryoSat Ocean Products (COP) are carried out by the Technical University of Delft (TUD, NL). Reports are delivered on a bi-yearly basis and available only internally. During the reporting period, the TUD report covering the period February - December 2020 was consolidated and reviewed by ESA.

The National Oceanography Centre (NOC, UK) produces complementary validation reports on ocean L2 data (NOP, GOP and IOP) including reprocessed datasets.

The NOC reports are publicly available on the NOC web site. A draft of the peer reviewed paper, on Level 3 NOC sea level anomaly product, has been submitted to ESA and collaboration with a tsunami modeller for 2018 Palu Tsunami study has started.

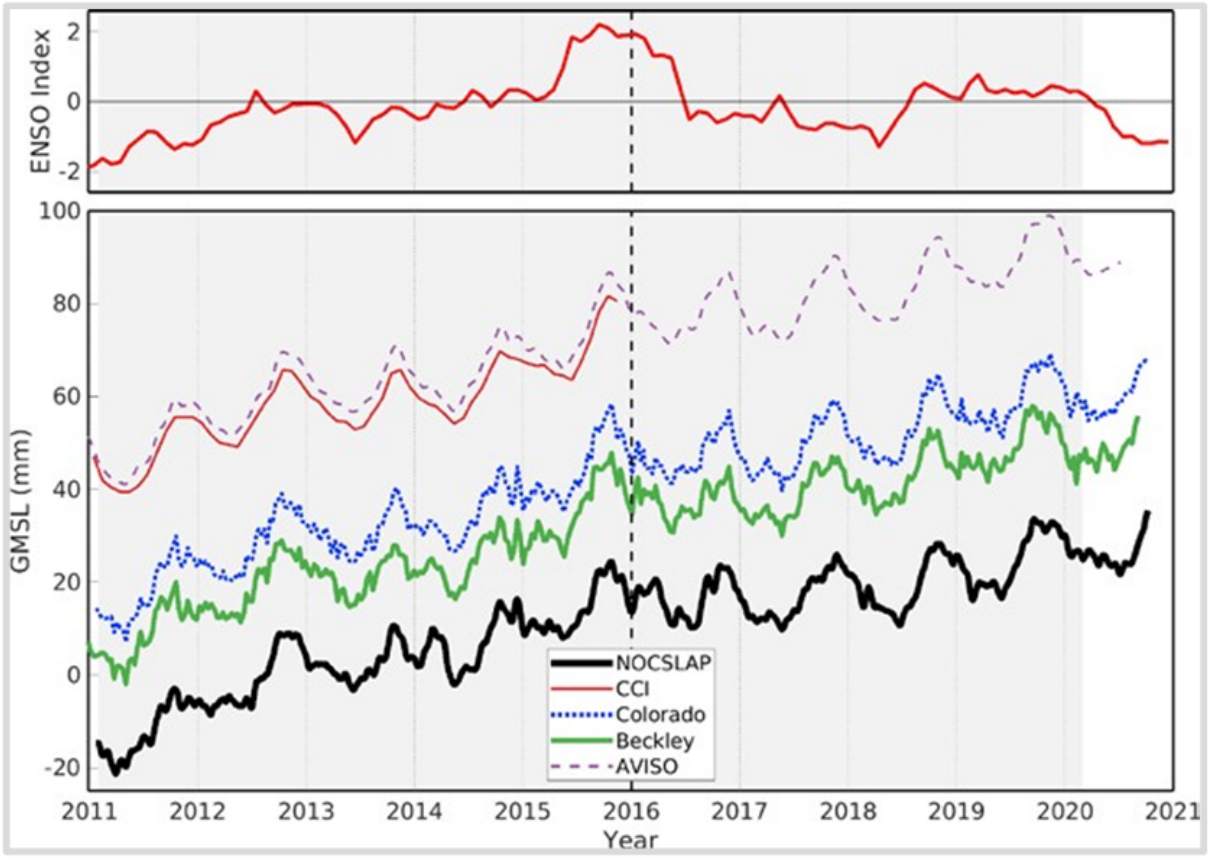

Figure 5: *Top panel shows Multivariate ENSO Index (MEI.v2; https://psl.noaa.gov/enso/mei/). Lower panel is Global mean sea level from CryoSat NOCSLAP, ESA CCI v2, Colorado, Beckley et al, and AVISO.*

An analysis was by ARESYS to verify the performance performed of SIRAL in terms of range resolution by analysis of transponder acquisitions and verify that it still within the following interval [0.394m - 0.436]. It has been verified that for SAR mode the average range resolution for all the acquisitions over Svalbard transponder is 0.4244±0.0057 m.
A new analysis performed by ARESYS on the CryoSat passes over the Svalbard and the Crete CDN1 transponder allowed to reconciliate the range bias, measured on the different transponders and for different instrument modes, since the beginning of the mission and its variation in time:

- Svalbard transponder
  - SARin Rx1: range bias 38.5±20.3 mm
  - SARin Rx2: range bias 38.1±20.1 mm
  - SAR: range bias 24.7±1.5 mm
- Crete CDN1 transponder
  - SAR: range bias 33.0±20.7 mm

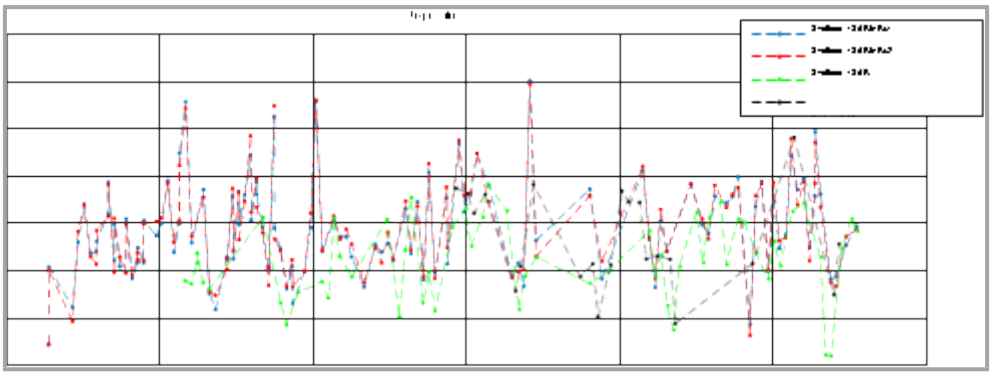

Figure 6: *Long-term range bias measured from passes over different transponders.*

An independent quality control of the SIRAL radar parameters is also periodically performed by IsardSat (ES), throughout the processing of the Transponder data over Svalbard and Crete. Reports are only available internally.

Since the CryoSat-2 orbit alignment with IceSat-2, several weeks of winter data (from 1st October to 11th November 2020) have been made available to measure sea-ice parameters with a KuLa (Ku-radar band Laser) approach. Current work, led by LEGOS (FR) and QA4EO SERCO team (IT), is focusing on understanding the freeboard differences between the two measurements. In particular, the relative contributions of the Ku-band penetration, surface roughness and the altimetric footprint size. It is essential to assess the potential issues of

KuLa-based approaches to retrieve snow depth and ultimately provide high accuracy sea-ice thickness. These preliminary studies will be more statistically relevant once the sea-ice freeboard data (ATL07/ATL10) from NASA is released in the next reporting period.

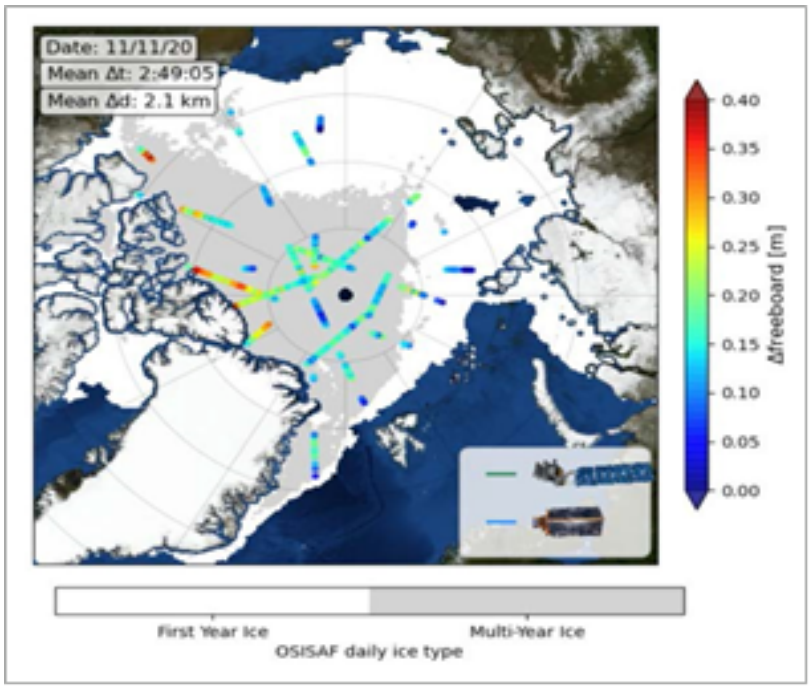

Figure 7: *Map of freeboard difference between CryoSat-2 and IceSat-2 for collocated tracks from the 28/10/2020 to 11/11/2020.*

Data Quality:

The CryoSat ice and ocean data products are routinely quality-controlled and thoroughly validated:

- Ice Chain: No major issues to report. The quality of the ice products is optimal
- Ocean Chain: No major issues to report. The quality of the ocean products is optimal

As already announced to the user community, FDM data were decommissioned at the end of January and replaced by NOP data (i.e. Near Real time data from the Ocean Chain).

Calibration and Validation Campaigns

Transponder calibration over-flights were performed over the Svalbard and Crete transponders according to the annual campaign plan.

CryoVex2021, planned for the beginning of April in the Arctic, has been cancelled once again due to COVID and - as consequence - the closure of the bases in Greenland. Plans are underway for a Spring 2022 campaign where we will benefit from a joint collaboration with Canadian sea-ice ground-based measurement activities, while still targeting Cryo2ice tracks. Some discussion for an Antarctica campaign in November 2022 has taken place with possible confirmation around end of this year.

3.4 SWARM

Swarm is the fourth Earth Explorer Opportunity Mission of ESA's Earth Observation Envelope Programme. This constellation of three satellites is designed to measure the magnetic signals that stem from Earth's core, mantle, crust, oceans, ionosphere and magnetosphere.

3.4.1 Status of spacecraft

The Swarm mission has overall remained nominal throughout the ongoing Covid- 19 pandemic.

Overall, the three spacecraft performed nominally during the reporting period. However VFM on-board Swarm-C was switched off automatically by the Platform on 19 March 2021 because the data it provided had become erratic. After an Instrument power reset commanded by the Operations Team on 22 March, nominal performance resumed, pointing to an SEU as the cause of the anomaly.

The platforms have been performing well during the reporting period and are in excellent condition. Occasional minor gaps in dumped data and single events mostly caused by radiation or plasma irregularities have only a negligible impact on data availability and mission performance.

A constellation manoeuvre was performed in February 2021 with Swarm-A to maintain the separation of the lower pair between 5 – 10 seconds.

The planning for the counter-rotating orbits phase, with all three satellites in the same orbital plane but Swarm-B rotating in the opposite direction to Swarm-A and Swarm-

C, has started. A special constellation configuration will be implemented for the lower pair between June and December 2021.

3.4.2 Performance and results

All Vector Field Magnetometers (VFMs) as well as the Swarm-A & -B Absolute Scalar Magnetometers (ASMs) continue to perform extremely well, resulting in truly excellent magnetic field data. The extremely high quality of the magnetometer data in combination with high time resolution, from a constellation of three satellites, are the pillars of the Swarm mission success.

Non-permanent degradation in image quality remains present on all Electric Field Instrument Thermal Ion Imagers, preventing continuous acquisition of highest-quality science data. The current work- around operational scenario that allows the acquisition of valuable scientific data consists in keeping the instruments in nominal (i.e. high voltage) operation only partially, namely eight consecutive daily orbits on Swarm-A & -B and three consecutive daily orbits on Swarm-C.

All ingestion, Level 1 and Level 2 processing, archiving, and dissemination functions are running nominally and the production is fully current. During the period from mid-December 2020 to mid-March 2021 the performances of the Level 1 processing (computed as the percentage of successful job orders when input data is available) were optimal for all Level 1 processors: ORBATT (100%), ACCELE (100%), MAGNET (100%) and PLASMA (100%). For Level 2, the processing performance was also 100% with the EEF daily production being carried out by the University of Colorado since mid-March 2020. The actual data availability (taking also into account spacecraft tests, instrument problems, failures in previous processing steps, and missing auxiliary files) was 99% for Level 1 data mainly due to ACC switch off on Swarm-A from 28/12/2020 to 05/01/2021, and 100% for Level 2 products.

With regard to the Level 2 Cat-2 processing, the operational pipeline is generating on a daily basis Field Aligned Currents (FAC) derived from single and combined spacecraft measurements, Total Electron Content (TEC), and an Ionospheric Bubble Index (IBI).

All data products are routinely made available to both Cal/Val teams and general users through the Swarm dissemination server.

The production of the Level 2 Cat-1 fast-track magnetospheric field model, the precise science orbits and non-gravitational acceleration and thermosphere neutral densities determined solely from GPSR data is current and products are made available to users on a routine basis.

During the first quarter of 2021, more than 7.6 TB of Swarm data products - corresponding to more than 1.2 Million of files - have been distributed to the users. In order to simplify the access to the Swarm data, since summer 2018 all validated Level 1 and Level 2 products are freely accessible to any user via anonymous ftp/https. Since March 2019, the ESA Swarm dissemination server is also hosting a mirror of the CASSIOPE/e-POP full data archive (past and current observations) in native format. This improves the e- POP data accessibility, especially for European users.

Finally, the new Level 1 and Level 2 operational processors and latest auxiliary data to be used in the forthcoming full mission reprocessing have been fully validated, and the DPGS reprocessing chain is ready for the execution of this full Level 1 and Level 2 reprocessing campaign in Q2 2021. The initial end-to-end test has been completed, and the quality of the results are being analysed. This will provide fully consistent product datasets, reflecting all the latest improvements in the algorithms and calibrations.

e-POP and Swarm multi-mission synergies

Interactions and discussions on the Cassiope e-POP (Swarm Echo) magnetic data calibration correction process and data format are on-going. In this respect, the e-POP team is currently reprocessing a test data set of MGF 1 Hz and 160 Hz covering 2018 and 2019 to be shared with the Swarm User community for feedback.
Beyond e-POP, the Swarm expert community is furthermore consolidating the observational and technical material for new multi-mission data products complementary to Swarm, such as platform magnetometer data from the CryoSat, GOCE, Grace, Spire, DMPS and Iridium satellites. During the reporting period, the calibration of magnetic data from GRACE, GOCE and GRACE satellites has been finalised and published in Earth Planets Space (EPS). The data are made available to the whole Swarm community as daily files in “Swarm-like” CDF format. Another publication has been published in Earth Planets Space on co-estimation of geomagnetic field model plus satellite magnetometer calibration and alignment parameters, with application to Swarm, CHAMP, CryoSat-2 and GRACE magnetic data. Meetings between CryoSat-2 and Swarm technical team have allowed to design operational access to data needed for calibration and pre-processing of CryoSat-2 magnetic data on a regular basis

3.5 AEOLUS

Launched on 22 August 2018, Aeolus is the first satellite mission to acquire profiles of Earth’s wind on a global scale. The primary objective of the Aeolus mission is to demonstrate the Doppler Wind Lidar technique to measure wind profiles from space. The mission sets out to provide observations of global wind profiles along the instrument line of sight (LOS) direction over a minimum lifetime of 3 years. The data will be assimilated into NWP models, to improve the analyses and forecasting of the 3-D vector wind field. A secondary mission objective is to provide data sets suitable for the evaluation of climate models.

3.5.1 Status of spacecraft and mission

The total operational time of the ALADIN instrument has been 30 months corresponding to around 3.7 billion laser shots (1.1 and 2.7 billion shots for FM-A and FM-B respectively).

On 22 March 2021, ALADIN entered Survival Mode. The transition was triggered by a failed consistency check by the application software on the operational mode of the instrument during an Instrument Spectral Calibration (ISR). At the time of writing this report, a major effort to return the instrument to be fully operational at high energy is

currently underway. Until this event, the second flight laser transmitter (FM-B) continued to perform well in terms of UV output energy currently around 68mJ.The main focus on the ALADIN instrument is to recover the long-standing decrease of atmospheric return (and internal) signal. Around 45% of atmospheric return signal has been lost since the switch-on of FM-B, with strong indication that most of the reduction is caused by the clipping of the signal at the instrument field stop. As part of the recovery roadmap, two major tests were performed in the first quarter of 2021: the thermal sensitivity test on the M1 telescope and the change of the temperature set-points on the top-floor of the platform. Unfortunately, none of them have brought the desired expected increase of signal. For the latter test, there is, however, indication that the robustness of the thermal system has been increased with respect to signal return fluctuations entering and exiting an eclipse. A study to review options, feasibility, pros and cons of lowering the orbit is ongoing with industry. A target orbit of 256 km has been now identified with a baseline scenario to decay the orbit naturally. Results are expected in June 2021. Meanwhile, a number of internal checks and investigation, covering impact on all domains (e.g. ground segment, mission planning, processing, data quality) are being carried out. A dedicated workshop is planned at the end of June in order to consolidate the choice to switch back to the first flight laser (FM-A) and to lower the orbit using the inputs from this study.

The Doppler Wind Lidar technique used for measuring wind profiles from space has already been fully demonstrated. The positive impact on the weather forecast has been also seen by multiple NWP centres world-wide, although longer unbiased datasets are still necessary in order to achieve statistically significant results representing also multiple seasons. A new systematic L2B Quality Management Service was rolled out at ECMWF which extracts the number of winds from L2B products and compares it against pre-defined reference threshold values to determine if the product is in line with quality requirements.

The Tropical Aeolus Cal/Val campaign activities have been postponed from July 2020 to July 2021. The preparation of the individual campaign elements is supported by regular meetings during the reporting period, ensuring the close coordination between all partners and specifically monitoring the evolving Covid-19 situation and regulations in the participating states and Cape Verde and be ready to cancel the campaign.

3.5.2 Performance and results

After the anomaly occurred on 22 March 2021, the laser switched from Measurement to Survival mode and no telemetries suitable for processing could be acquired since this date. Prior to the satellite on-board problem, the Aeolus Ground Segment performed nominally for all core functions including data acquisition, mission planning, systematic data production, data access, data archival.
X-band data acquisition for all Aeolus passes was guaranteed with the combined usage of Svalbard and Troll stations. In total, 99,92% of the scheduled Aeolus passes were successfully acquired in 2021 and 99,41% of the systematically processed L1B data products were made available to ECMWF and Aeolus Cal/Val

community in far less than 3 hours from sensing, demonstrating the maturity of the L1B NRT service.
The overall production completeness of L2A, Optical properties profiles, was 100% and 99.41% of L2B products, which is the primary mission product, were generated in NRT at ECMWF and distributed successfully to Aeolus data users within 3 hours from data sensing.

Since May 2020, users can directly access publicly available Aeolus wind products either through the ESA Aeolus Online Dissemination Service http://aeolus-ds.eo.esa.int/oads/access/ or through ftps://aeolus-ref-addf.eo.esa.int .

Aeolus users can also access wind data through EUMETCast, EUMETSAT's primary dissemination mechanism and through the Global Telecommunications System (GTS) of WMO in BUFR format.

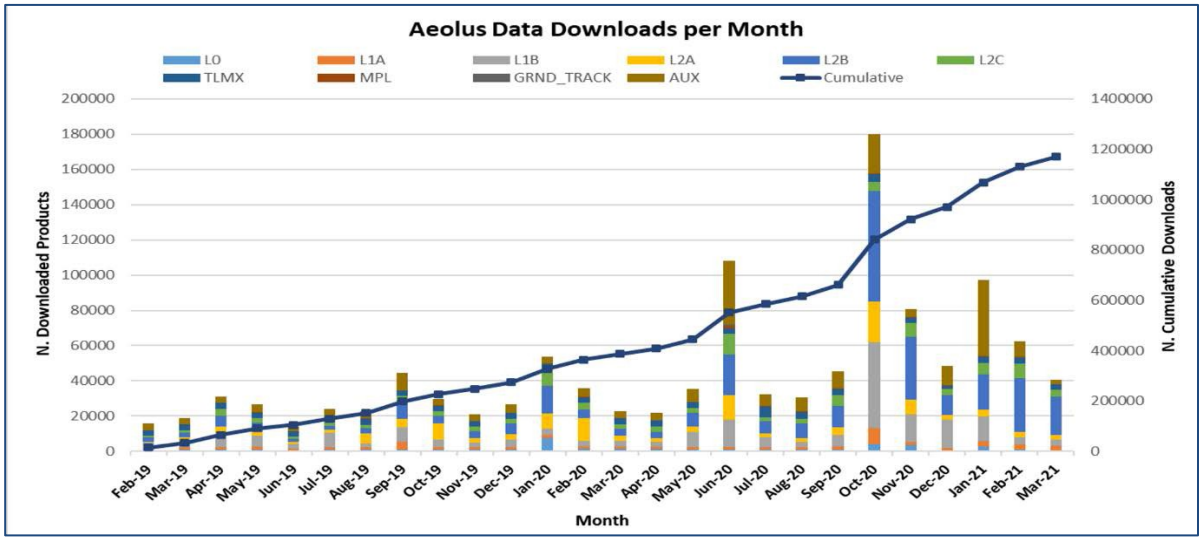

Figure 8: *Aeolus Data Download from ESA Aeolus Online Dissemination Service*

Since the public release of data, all users can explore and analyse Aeolus L1B and L2B NRT data further through VirES (https://aeolus.services) which is a highly interactive data discovery, exploitation and visualisation web-based client application tool for Aeolus products.

A new systematic L2B Quality Management Service was rolled out at ECMWF which extracts the number of winds from L2B products and compares it against pre-defined reference threshold values to determine if the product is in line with quality requirements. This also helps to detect any quality issues at the earliest in case of unexpected biases after instrument maintenance activities.

In January 2020, ECMWF started assimilating Aeolus wind data into their operational weather forecast suite, marking it as one of the most important milestones in accomplishing mission objectives. L2B processing configuration parameters were fine-tuned three times at ECMWF with the purpose of improving Rayleigh bias correction in the L2B products.

The new L2A Aerosol/Cloud processor features the additional new advanced feature mask AEL-FM which is based on the A-FM feature mask developed by KNMI for the EarthCARE project for ATLID. Furthermore, this L2a processor version is foreseen to

be the basis for the public release of the L2A product foreseen for the second quarter of 2021.

Monthly data quality reports for the publicly available L2B wind product are available via the Earth Online Aeolus site, while the weekly statistics from NWP monitoring remain available via ECMWFs website. Periods of known potential product quality degradation (e.g. due to special instrument operations) are being block-listed via the new flagging mechanism introduced with B11 to avoid usage for NWP centres. Once known, these periods are announced via the Cal/Val wiki as well as via email to NWP users.

In response to the COVID-19 pandemic, the Tropical Aeolus Cal/Val campaign activities have been postponed from July 2020 to July 2021. It will include the German DLR Falcon-20 with the A2D and 2-µm Doppler wind lidars, the French Safire Falcon- 20 with payloads including the LNG lidar, the RASTA Radar system and in-situ aerosol instruments under the scientific lead of LATMOS/CNRS, a Light Aircraft with in-situ aerosol instrumentation under the scientific lead of the University of Novo Goriza (SI), and extensive remote and in-situ ground-based and drone-borne observations, including the EVE ground-based Raman Lidar, coordinated by the National Observatory of Athens, which has successfully passed its acceptance review during the reporting period. The European activities will be complemented by the NASA DC- 8 aircraft carrying lidar and radar systems.

The preparation of the individual campaign elements is supported by regular ESA/NASA meetings during the reporting period, ensuring the close coordination between all partners and specifically monitoring the evolving COVID-19 situation and regulations in the participating states and Cape Verde.

Aeolus winds over the North Pole were used to follow the sudden stratospheric warming and polar vortex split in December 2020 and January 2021.

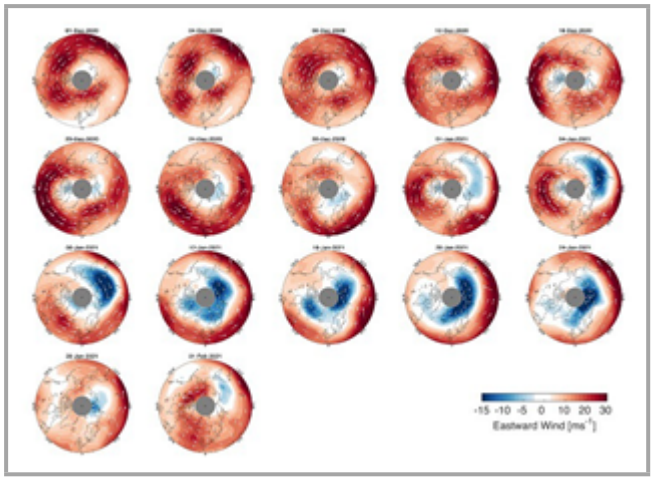

Figure 9: *Based on data from ESA's Aeolus wind mission, the image shows how the polar vortex in the lower stratosphere changed between 1 December 2020 and 1 February 2021. The first few plots at the beginning of December show the vortex in a comparatively normal state, but in mid-December patches of blue wind appear, and the wind is going westwards relative to normal conditions. Courtesy, C. Wright (University of Bath).*

Atmospheric gravity waves have been characterized from Aeolus wind shear measurements in South America and the South-East pacific. The findings were supported by simultaneous vertical temperature perturbations measured by the on-ground temperature lidar CORAL at the EARG Station in Rio Grande, Tierra del Fuego, Argentina. The work has been submitted to Geophysical Research Letters.

ECMWF forecast impact assessment of Aeolus re-processed data from July and August 2019 show that Aeolus is the second most important satellite instrument and provides greater impact than radiosondes. More details on the benefits of Aeolus data in the NWP can be found in an ECMWF paper "*The impact of Aeolus wind retrievals in ECMWF global weather forecasts*" submitted to the Quarterly Journal of the Royal Meteorological Society (QJRMS) in January 2021. Besides, the University of Bath and partners have submitted the paper "Atmospheric Gravity Waves in Aeolus Wind Lidar Observations" to Geophysical Research Letters (GRL) in February 2021.

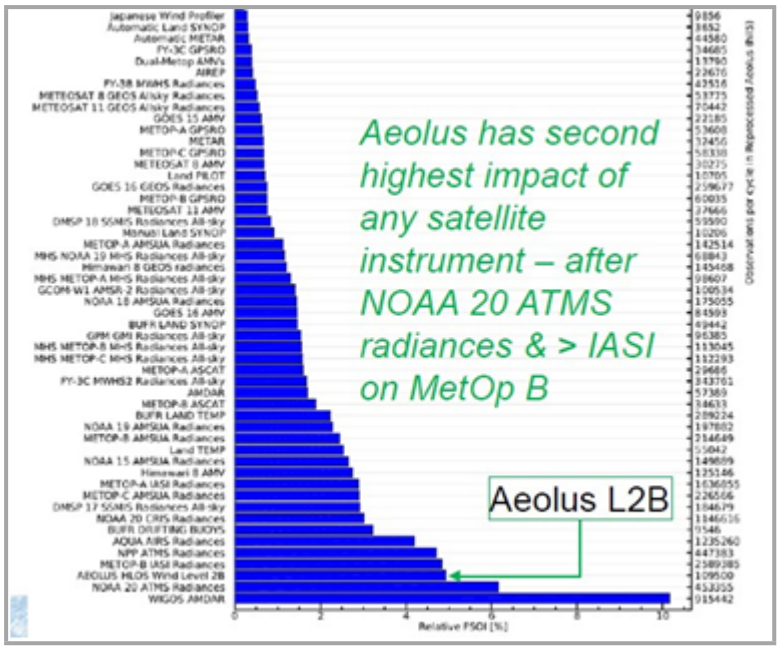

Figure 10: *Forecast Sensitivity to Observation Impact (FSOI) statistics from Observing System Experiment (OSE) at ECMWF for July and August 2019. The FSOI statistics shows the short-range forecast impact per instrument assimilated at ECMWF. Aeolus L2B winds are ranked as the instrument with the 3rd most impact. With courtesy, M. Rennie, ECMWF.*

The UK MetOffice started to operationally assimilate Aeolus Mie winds (particle backscatter wind channel) on Tuesday 8 December 2020. At the 3rd meeting of the Aeolus Science & data Advisory Group (SAG) on 4-5 March 2021, they reported a positive benefit in all regions, most marked in the tropics and improved first of the model to other observational datasets. The positive impact was demonstrated for two Observing System Experiments (OSE) in 2020 for two different seasons.

The Indian NCMRWF plans to start operational assimilation in spring 2021.

ESA is going to initiate a series of scientific studies such as include e.g. Aeolus wind assimilation and NWP impact in regional models, Aeolus data impact on severe weather events, an atmospheric process study, and scientific analysis of the results from the upcoming Tropical campaign. The activity "Aeolus data impact on severe weather events" has been negotiated and will be kicked-off on 1 July 2021.

The study on the assimilation of the Aeolus aerosol product in CAMS (A3S) was kicked off in October 2019. Aeolus L2A observations have been successfully assimilated in the most recent CAMS cycle in the research department at ECMWF, and impact experiments have been performed. A positive impact of Aeolus L2A data

was seen on the CAMS forecast was seen in global statistics, and further impact experiments using reprocessed Aeolus L2A data (with less noise and improved error estimates) was recommended. The Final Presentation was held on 29 January, and discussions for a potential continuation within the Aeolus DISC and for EarthCARE are on-going.

4 STATUS OF CURRENT EARTH WATCH SATELLITES

The Earth Watch programme encompasses the development of the series of operational meteorological satellites of EUMETSAT (not covered in this report), the Proba series of small satellites for medium-resolution imagery, and the Copernicus programme of Sentinel satellites designed to provide reliable, timely and accurate services to manage the environment, understand and mitigate the effects of climate change and help respond to crises.

4.1 Proba-V

Launched on 7 May 2013, Proba-V is tasked with a full-scale mission: to map land cover and vegetation growth across the entire planet every two days. Proba-V is flying a lighter but fully functional redesign of the 'Vegetation' imaging instruments previously flown aboard France's full-sized Spot-4 and Spot-5 satellites, which have been observing Earth since 1998. The Spot Vegetation dataset had close to 10,000 registered users around the globe and has contributed to hundreds of scientific papers over 15 years. But with further Spot satellites lacking the capacity to carry Vegetation instruments, Proba-V has been designed to meet the future needs of this group. Proba-V's Vegetation instrument boasts improved spatial resolution from its Spot predecessors: 350 m resolution compared to 1 km for Spot Vegetation, with 100 m resolution available within its central field of view. In fact, at that time the full Sentinel-3 constellation (A+B) is expected to be ready to ensure continuity to the SPOT-VGT and Proba-V long-term archive and to address the needs of the land community, in particular of the Copernicus Global Land Service (CGLS).

Proba-V provides data to the instrument's worldwide user community of scientists and service providers. Uses of Proba-V Vegetation data include day-by-day tracking of extreme weather, alerting authorities to crop failures, monitoring inland water resources and tracing the steady spread of deserts and deforestation.

4.1.1 Status of spacecraft

The Proba-V mission proceeds in its experimental phase, which has started on 1 July 2020, with a reduced acquisition scheme focusing on Africa.

Preparation is intensifying for the operations of the Proba-V Companion Smallsat.

During the reporting period the Proba-V spacecraft was operated nominally and was very stable. All key on-board parameters have been well within their design margins, i.e. power, thermal, pointing, processing and memory. No platform and payload degradations have been detected. The Vegetation instrument acquisition and calibration requests have been performed nominally. As part of the experimental

phase, moon calibration observations around the time of the full moon took place successfully during January, February and March.

The investigation performed by VITO about the number of geometric errors has shown that the actual impact on the final product was very limited. The amount of these errors is gradually decreasing with the seasonal effect.
All the key parameters on-board have been well within their design margins, i.e. power, thermal, pointing, processing and memory. No platform and payload degradations have been detected. The Vegetation Instrument acquisition and calibration requests have been performed nominally. The number of decompression errors remains very low and stable.

4.1.2 Performance and results

Acquisition performance is mainly stable with occasional passes containing a few frame gaps and no failed passes during the reporting period. The number of daily downlink passes continues to be three.

Radiometric and Geometric Quality
No major issues were observed during the reporting period on both the radiometry and geometry calibration, the quality of the data is therefore at stable level with no sign of degradation.
The radiometric accuracy remains stable and well within mission goal requirements (better than 3%). Proba-V radiometric accuracy remains at the same level of more sophisticated sensors equipped with on-board calibration devices, such as MODIS or Sentinel-2. The modelling of the detector sensitivity degradation throughout the mission lifetime was finalised by VITO and the updated calibration files (ICP) were consolidated. They are now available for the start of C2 reprocessing.
Concerning the geometric accuracy, the nominal monitoring of Absolute Location Error (ALE) is continued during the Experimental Phase, though with reduced number of Ground Control Points, owing to the limited spatial coverage. The geometric accuracy remains extremely good and stable in time with average ALE of the order of 70 m.

The **Collection-2 baseline** includes improvements to the cloud and cloud shadows screening methods. The development of Collection-2 (C2) Baseline is completed and the first validation dataset, consisting of 5 days of globally reprocessed data, was generated by VITO. It is currently under evaluation.

The results presented so far were really encouraging, since the full processing chain (from L0 to L3) is functioning as expected, although an increase in computational time is verified. This increase was foreseen and mostly driven by the more sophisticated algorithms being used in C2, notably the advanced atmospheric correction and cloud screening modules. On the other hand, in terms of data quality, the C2 products clearly outperform the C1 products. An example is presented in Figure 11, where the cloud (yellow) and snow/ice (red) mask is presented over a mountainous scene in the Alpine region. The over-detection of clouds, which was a known issue in C1 dataset, is clearly presented over this scene, where clear/land and snow/ice pixels are very often wrongly flagged as cloudy. The C2 machine learning

algorithm, developed by University of Valencia (Spain), dramatically improves the cloud detection accuracy, as can be observed in the example scene. Several applications are expected to benefit from such improved accuracy, notably land vegetation monitoring, but also snow mapping applications. Likewise, the new atmospheric correction scheme provides significant improvements in the accuracy of Top-Of-Canopy (TOC) reflectances, in particular by removing the spatial and temporal inconsistencies observed in C1.

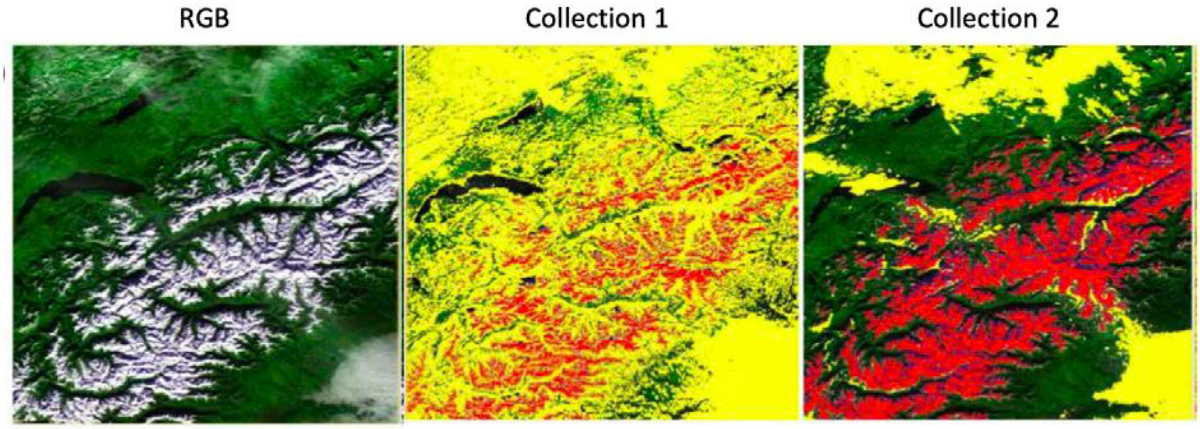

Figure 11: *Cloud mask (yellow) and snow/ice mask (red) for C1 and C2 data.*

Based on these preliminary results, the C2 baseline proves to be a major upgrade in terms of data quality as compared to C1. The go-ahead for the bulk reprocessing will be decided during the forthcoming QWG meeting, after review of the final verification results.

The full reprocessing is expected to last 6 months; however, early access to one year of data will be granted to Copernicus Global Land Service in order to perform a cross-validation with Sentinel-3 derived geophysical products. Validation of C2 data will continue in parallel to the reprocessing campaign. Accuracy of C2 TOC products will be validated by benchmarking to MODIS data and the temporal and spatial consistency of the products will be evaluated at global scale following the methodology already adopted for C1. The target is to complete the full validation by the end of the reprocessing, by end 2021, to be able to certify the quality of the full archive before opening the C2 data to the users. The overall validation results will be summarised in a scientific paper.

Preparation of Proba-V Companion Smallsat operations The experimental phase has started on 1 July 2020. An important stage of the Proba-V experimental phase is the operations of a companion smallsat (PV-CC), embarking a spare Proba-V camera, developed by Aerospacelab (ASL). Regarding the PV-CC launch, the date will be either in December 2021 or mid-2022, depending on the launcher used. Until the launch of the first companion smallsat, embarking a Proba-V spare camera, developed within the ESA GSTP programme and currently scheduled to be launch in April 2021, Proba-V experimental mission will be essentially focused on Africa data acquisitions (about 3 orbits/day) with emphasis on 100 m data.

The rationale to select the Africa 100 m experimental activity lies in the following points:

- It spans a latitude interval (35°N/35°S) less affected by the orbital drift (with related increase of Sun Zenith Angle),
- It builds on the past experience that Proba-V 100 m data acquisition over Africa brings added value with respect to standard coarse resolution sensors,
- It is relevant for various applications: land cover, forestry, crop mapping and food security,
- It includes desert sites and RadCalNET (Gobabeb) site, allowing to continue radiometric calibration monitoring,
- Because of its experimental nature, it is affordable and in line with reduced operations costs during the experimental phase (3 passes/day).

Data will also be acquired with side cameras (300 m data) to complement 100 m data in challenging regions, e.g. through experimental data fusion or super-resolution methods.

In addition to the main experiment (Africa 100 m), the experimental mission will also include the following activities:

- Cal/val activities: sensing on the moon, yaw manoeuvres,
- Public Relation: elaboration of Proba-V mission book,
- Multi View Angle (not enough overlap) and Antarctica sensing will not be performed (Sentinel-2 and Sentinel-3 missions already ensure an excellent coverage of Antarctica).

Further information about Proba-V products can be found in Earth Online portal[1].

5 THE COPERNICUS SENTINEL PROGRAMME

5.1 Sentinel-1A and 1B

The Sentinel-1 mission is a polar-orbiting satellite system for the continuation of Synthetic Aperture Radar (SAR) operational applications. Sentinel-1 is a C-band imaging radar mission to provide an all-weather day-and-night supply of imagery for GMES user services. The SAR will operate in two main modes: Interferometric Wide Swath and Wave. The first has a swath width of 250 km and a ground resolution of 5×20 m.

The first Sentinel-1A satellite was successfully launched on 3 April 2014 and commissioned in September 2014. The second Sentinel-1 B was launched on 25 April 2016 and commissioned in September of the same year.

The Sentinel-1 routine operations continued and the overall performance was steady during the quarter. The occurrence of satellite anomalies and mission unavailability periods remained very limited during the reporting period.

[1] https://earth.esa.int/web/guest/data-access/browse-data-products/-/asset_publisher/y8Qb/content/proba-v-1km-333m-and-100m-products

The Sentinel-1 constellation observation scenario supports the systematic coverage of Copernicus Services areas of interest, of European land and coastal waters, of global tectonic & active volcanic areas, as well as of other specific areas worldwide for various applications. The observation plan includes regular mapping in dual polarisation of all land areas worldwide, with a frequency of 12 days or better (except the inner parts of Antarctica which are subject to specific campaigns). Over Europe, the constellation provides a full coverage at least every 6 days, both in ascending and descending orbits (with a few exceptions during the winter period regarding the Baltic Sea, related to the needs from the Copernicus Marine Environment Monitoring Service (CMEMS). The observation scenario also includes a number of specific acquisitions in various SAR operational modes over a limited number of calibration and validation sites to support the Mission Performance Centre operational activities (including cal/val, routine product quality control, etc).

The specific observation scheme (performed with Sentinel-1B, using the Extra Wide Swath mode in horizontal polarisation HH+HV) that supports the needs of CMEMS for sea-ice monitoring in the Baltic Sea during winter, started on 20 November 2020 and is planned to be completed by early May 2021.

The Greenland yearly observation campaign, aiming at covering the inner part of Greenland with 6-day repeat passes for 4 consecutive passes at least, using Sentinel-1A and Sentinel-1B, started mid-December 2020 and was completed at the end of January 2021. Related observations allow experts to generate Greenland ice sheet-wide ice velocity maps, an activity which has been included in the Copernicus Climate Change Service. The Canadian ice caps yearly campaign was made subsequently between early February 2021 and mid-March 2021.

During the reporting period Sentinel-1 contributed again to several emergency events (floods mainly), in particular in response to activations from the Copernicus Emergency Management Service and from the International Charter Space and Major Disasters.

The mission routinely generates a total daily production exceeding 13 TB. The EDRS service is operationally used for both Sentinel-1A and Sentinel-1B. Sentinel-1 data can be accessed from https://sentinels.copernicus.eu.

World maps from May 2019 provide a high level description of the overall Sentinel-1 constellation observation scenario, in terms of SAR modes, polarisation, observation geometry, revisit and coverage frequency. These maps are still valid and are available at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario

The detailed observation plan in the form of acquisition segments is published at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-1/observation-scenario/acquisition-segments

By 22nd April 2021, a total of 449,239 users have self-registered on the Sentinels Open Access data Hub; 33.8 million Sentinel-1 product download have been made by users, representing 42 PB of data. 6.5 million Sentinel-1 products are available on-line for download, representing 10.5 PB of data.

5.2 Sentinel-2A and 2B

A pair of Sentinel-2 satellites routinely deliver high-resolution optical images globally, with 5-day revisit, providing enhanced continuity of SPOT- and Landsat-type data. Sentinel-2 carries an optical payload with visible, near infrared and shortwave infrared sensors comprising 13 spectral bands: 4 bands at 10 m, 6 bands at 20 m and 3 bands at 60 m spatial resolution (the latter is dedicated to atmospheric corrections and cloud screening), with a swath width of 290 km.

The Sentinel-2A satellite was successfully launched by VEGA (VV05) on 22 June 2015 and the Sentinel-2B also by VEGA (VV09) on 6 March 2017.

In accordance with the Copernicus data policy, Sentinel-2 data products are made available systematically and free of charge to all data users including the general public, scientific and commercial users. Sentinel-2 products are in Sentinel Standard Archive Format for Europe (SAFE) format, including image data in JPEG2000 format, quality indicators, auxiliary data and metadata.

The Sentinel-2 operations continued nominally and the overall performance was very good. The overall status of both Sentinel-2A & Sentinel-2B functional health is very good, with few anomalies and little, if any, evidence of any long-term degradation. Both the OCP units continue to suffer periodic outages due to radiation sensitivity, but mitigation measures have been put in place minimizing unavailability periods. The Ground Segment operations sustained very good levels of performance.

On 30 March 2021, a major improvement was introduced on the geometric quality of Sentinel-2 products, having now a more accurate absolute geolocation and multi-temporal registration. The improvement is in place over Europe and Africa and it will be progressively extended to the rest of the World in the coming months. With this change also the following aspects of Level-1C and Level-2A products have been improved for the whole production:

- Use of the new 90 m Copernicus Digital Elevation Model (DEM).
- Improvement of the Level-1C cloud detection algorithm over high-altitude terrains
- Improvement of the Level-1C Technical Quality (TECQUA) mask accuracy
- Improvement of the Level-2A cloud probability layer near the boundary of the swath
- Improvement of the Level-2A topographic correction thanks to the use of the Copernicus 90 m DEM
- Correction of a light halo observed along Level-2A image boundaries, either at the edge of the swath or at the end of data-strips.

An extended observation scenario beyond the HLOP version 3.0 is being operated. Additional acquisitions include Northern Europe and some additional Arctic Areas in low-illumination conditions, additional Pacific Ocean islands (Tuamotu, Austral Islands, Kiribati), Bermuda Islands, Juan Fernandez Archipelago (Chile) and Sargasso Sea. The detailed observation plan, under the form of acquisition datastrips, is regularly published online at:

https://sentinels.copernicus.eu/web/sentinel/missions/sentinel-2/acquisition-plans

Since 13 December 2018, the Sentinel-2 surface reflectance (Level-2A) production is extended to a worldwide coverage. This expands the systematic production and distribution for the Euro-Mediterranean region that is available since 26 March 2018. The production of Level-2A surface reflectance products (for both Sentinel-2A and Sentinel-2B) is available on all Copernicus data distribution hubs, i.e. Open Access Hub, Collaborative Hub, Services Hub and International Hub.

In the framework of the Europe-US Earth Observation (EO) Collaboration on Land Imaging, a collaborative work programme is being implemented for better complementarity, cost reduction and increased efficiency. Regarding current operational missions, the collaboration is largely focusing on Sentinel-2 and Landsat. A workplan with actions has been defined with collaborative domains including: Data Acquisition & Initial Processing, Product Definition & Generation, Product Storage, Delivery, & Access Architectures, Calibration and Validation, User Needs & Requirements, and Specifications & Future Mission Architectures. Status and lessons learned from the Ground Segment transformation have been shared with the American counter-parts.

Activities related to CEOS ACIX-II and CMIX exercise, co-organised by ESA and NASA, continued during the reporting period. A first publication with the results from ACIX-II Aqua exercise has been published and is available at: https://www.sciencedirect.com/science/article/pii/S0034425721000845

Further details on ACIX II and CMIX exercises can be found on the following website: https://earth.esa.int/web/sppa/meetings-workshops/hosted-and-co-sponsored-meetings/acix-ii-cmix-2nd-ws

Regarding the downstream usage of Sentinel-2 data products, it is highlighted, as a major breakthrough, the usage of Sentinel-2 for methane emissions observation and quantification. This new application allows to accurately identify the location of methane sources, complementing the coarser global measurements from Sentinel-5P.

5.3 Sentinel-3A and 3B

The main objective of the Sentinel-3 mission is to measure sea surface topography, sea and land surface temperature, and ocean and land surface colour with high accuracy and reliability to support ocean forecasting systems, environmental monitoring and climate monitoring. The mission definition is driven by the need for continuity in provision of ERS, Envisat and SPOT-Vegetation data, with improvements in instrument performance and coverage. Sentinel-3A was successfully launched on 16 February 2016 and the commissioning phase was terminated in August 2016. Sentinel-3A passed its Routine Operations Readiness Review on 16 October 2017 and is now officially in routine operations, having reached full operational capacity already in July 2017.

Both Sentinel-3A and Sentinel-3B are in routine operations and the overall performance was good during the reporting period. There were no major anomalies

during the quarter, apart from a smaller anomaly on the OLCI instrument on-board Sentinel-3A which caused a data outage of about 15 hours on 5 March 2021.

Important efforts are made to ensure the continuity of the Sentinel-3 mission operations during the on-going Covid-19 crisis. Currently all instruments, including OLCI, SRAL, SLSTR and MWR, on both satellites, are switched on and performing well. All Sentinel-3A and -3B Level 1 and Level 2 core data products have been released to the user community.

The Sentinel-3 Land Ground Segment continued successfully the Sentinel-3A and -3B operations, including acquisition, processing and dissemination of data products while, as part of the on-going PDGS service operations, the transfer to the cloud was being finalised for all production related activities and data flows were modified to use public internet. All Sentinel-3 production is successfully performed on the cloud since January 2021.

The Sentinel-3 Land Ground Segment continued successfully the Sentinel-3A and -3B operations, including acquisition, processing and dissemination of data products while, as part of the on-going PDGS service operations, the transfer to the cloud was being finalised for all production related activities and data flows were modified to use public internet. All Sentinel-3 production is successfully performed on the cloud since January 2021. The mission routinely generates a total daily L1/L2 production of ~2.5 TB.

All Sentinel-3A and -3B Level 1 and Level 2 core data products are operationally released to the user community and made available via the Open Hub. The Fire Radiative Power (FRP) products are since 19 August 2020 made available to all users through the regular Data Hubs (https://cophub.copernicus.eu/news/News00478).

The Sentinel-3B Level 1 and Level 2 SLSTR data acquired during the commissioning period have been reprocessed with the latest processing baseline and all output products have been made available to users on the Open Hub. Reprocessing of Sentinel-3A SLSTR is planned for Q2 2021.

5.4 Sentinel-5P

The Sentinel-5 Precursor mission will be a gap-filler, within the 2016-2023 timeframe, between the end-of-life of the current atmospheric chemistry mission (OMI on EOS/Aura) and the operational availability of Sentinel-5. As a joint initiative between ESA and the Netherlands, the mission will comprise a satellite and a UVNS instrument called TROPOMI.

The Sentinel-5P satellite has been launched by Rockot on 13 October 2017.

The TROPOMI instrument continues measuring in nominal baseline with a 360 orbit repeat cycle and is operated since 6 August 2019 with a spatial along-track resolution of 5.5 km (instead 7 km) providing since then ~20% more science data to the user community.

The overall thermal stability and radiometric performance of the TROPOMI instrument is very good with all systems operating nominally, and the SWIR instrument is considered to be very stable and in excellent condition.

Sentinel-5P has been flying in loose formation with SUOMI-NPP since December 2017 and VIIRS cloud information is used operationally in the Methane retrieval algorithm.

The products Level 1B Radiance/Irradiance, Tropospheric Ozone, Methane (Offline), Formaldehyde, Sulphur Dioxide, Carbon Monoxide, Total Ozone, Nitrogen Dioxide, Aerosol Absorbing Index, Aerosol Layer Height and Cloud products (Offline and NRT) are available to the public via the Copernicus Sentinel-5P Pre-Operations Hub (https://s5phub.copernicus.eu).

To support the ESA/EC and trilateral (ESA/NASA/JAXA) Covid-19 dashboards – https://race.esa.int, https://eodash-trilateral.eox.at – on the topic of Air Quality, a higher Level product (2 weekly averages of Nitrogen Dioxide measurements) is being generated operationally – https://maps.s5p-pal.com – using the Sentinel-5P Product Algorithm Laboratory (PAL) infrastructure.

For the first time ever Methane emissions from pipelines have been detected from space using Sentinel-5P/TROPOMI measurements, complemented by Sentinel-2:

https://www.esa.int/Applications/Observing_the_Earth/Copernicus/Sentinel-5P/Monitoring_methane_emissions_from_gas_pipelines

5.5 Sentinel-6 Michael Freilich (Jason-CS)

The Jason-CS satellites form the space component of the Jason Continuity of Service mission, within the Copernicus Space Component Segment 3. Jason-CS will extend high-accuracy ocean topography measurements well into the 2020s, thanks to the participation of all partners (EUMETSAT, ESA, CNES, NOAA and NASA/JPL).

The Poseidon-4 altimeter employs digital architecture and the simultaneous measurement in the advanced SAR mode as well as in the conventional pulse-width limited mode. The Advanced Microwave Radiometer, Climate Quality (AMR-C) will be an enhanced version of JPL's instrument used on Jason-2 and Jason-3. A major programmatic decision has been the abandonment of the High Resolution Microwave Radiometer (HRMR) studies.

The GNSS receiver optimised for Precise Orbit Determination will be an instrument derived from the Sentinel-3b GNSS receiver, while Radio Occultation (RO) capability will be satisfied by a NASA-provided GNSS-RO. Additionally a DORIS Receiver and a NASA-provided Laser Retro-Reflector Array will be embarked.

The **Sentinel-6A Michael Freilich** (Sentinel-6MF) has been launched from the Vandenberg Air Force Base, California, on 21 November 2020.NASA and NOAA jointly acting as the US party are responsible for providing the launch services for both Sentinel-6 A and B satellites, US payload instruments and ground segment support, and will contribute to the operations. The Commissioning phase is still ongoing. The Sentinel-6MF Poseidon-4 altimeter instrument High Power Amplifiers (HPA) shows a decreasing trend in signal power similar to the trends observed on Sentinel-3A and Sentinel-3B. The S6-MF HPAs are in fact spares of the Sentinel-3 batch. The Poseidon-4 altimeter instrument is already showing exceptional end-to-end performance, validating the technology step realized with the completely digital architecture.

The GNSS-POD receiver, tracking Galileo and GPS constellations for the first time in space, is showing excellent results, significantly improved by Galileo.

6 FUTURE ESA SATELLITE SYSTEMS

6.1 Future Earth Explorer and Earth Watch missions

The Earth Explorers are research missions designed to address key scientific challenges identified by the science community while demonstrating breakthrough technology in observing techniques. Involving the science community right from the beginning in the definition of new missions and a peer-reviewed selection process ensures that a resulting mission is developed efficiently and provides the exact data required by the user.

6.1.1 EarthCARE

ESA's EarthCARE (Cloud, Aerosol and Radiation Explorer) mission is the largest and most complex Earth Explorer to date, and will advance our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back into space and trapping infrared radiation emitted from Earth's surface. EarthCARE is a joint venture between ESA and JAXA (Japan Aerospace Exploration Agency).

EarthCARE will advance our understanding of the role that clouds and aerosols play in reflecting incident solar radiation back into space and trapping infrared radiation emitted from Earth’s surface. By acquiring vertical profiles of clouds and aerosols, as well as the radiances at the top of the atmosphere, EarthCARE aims to address these issues. The mission will employ high-performance lidar and radar technology that has never been flown in space before.

The mission has a design lifetime of three years, including a six-months commissioning phase. Launch is planned to take place in the in the first months of 2023.

After completion by the JAXA consortium of the non-redundant CPR (NR-CPR) acceptance test campaign and after a successful Consent to Ship Review, the NR-CPR was released for shipment from Japan to Germany. It arrived successfully at Airbus on 26 March and is currently being prepared and tested for formal handover to Airbus before the end of April 2021.

Preparations and executions of satellite level system functional tests are on-going as well as all preparations for the integration and testing of the NR-CPR on the platform.

Integration of the ATLID PLH Flight Spare was completed, but thermal vacuum testing was not yet started at Leonardo, further delaying the start of the life tests.

Manufacturing of MSI TIR camera thermal straylight hardware modifications suffered a major setback, forcing a remanufacturing of the baffles and a subsequent rescheduling of the modifications of the flight instrument. Application software modifications have been completed and were delivered to the prime for testing and upload to the flight model.

Manufacturing activities of all CPR High Voltage Grid Modulator modules, both the ones under JAXA consortium as well as the ones under ESA contract (N-HVGM), encountered major delays at Leonardo. A back-up plan is currently being implemented so that N-HVGM can remain a back-up solution in case of failure of the repaired HPT-A.

The kick-off of the launch service contract with Arianespace was successfully completed and the schedule for the upcoming activities and reviews agreed.

All separate L2 algorithm development contracts – APRIL, CLARA/ICERAD, DORSY have delivered the prototype processors and contracts are being closed. APRIL and DORSY prototype L2 processors have been successfully combined into a single processing chain. Results were presented in combined final presentations of all three activities in March 2021.

A new study activity “PEARL Cloud – Preparation of EarthCARE Assimilation of Radar and Lidar Cloud Observations” has been kicked off in October 2019 under a contract with ECMWF. The objective of the activity is to implement a full, four dimensional, variational data (4D-VAR) assimilation of EarthCARE radar reflectivities and lidar total attenuated backscatter profiles of clouds into the ECMWF operational forecast system and to complete all technical preparations for the operational assimilation of these observables.

6.1.2 Biomass

The Biomass mission was selected in May 2013 as the 7th Earth Explorer mission of its Living Planet programme. The satellite will be designed to provide, for the first time from space, P-band radar measurements optimised to determine the amount of Biomass and carbon stored in the world’s forests with greater accuracy than ever before. This information, which is poorly known in the tropics, is essential to understanding the role of forests in Earth’s carbon cycle and in climate change. These objectives will be achieved by measuring Biomass and forest height at a resolution of 200 m and forest disturbances at a resolution of 50 m.

Reliable knowledge of tropical forest Biomass also underpins the implementation of the UN Reducing Emissions from Deforestation and forest Degradation (REDD+) initiative – an international effort to reduce carbon emissions from deforestation and land degradation in developing countries. In addition, the measurements made by Biomass offer the opportunity to map the elevation of Earth’s terrain under dense vegetation, yielding information on subsurface geology and allowing the estimation of glacier and ice-sheet velocities, critical to our understanding of ice-sheet mass loss in a warming Earth. Biomass also has the potential to evolve into an operational system, providing long-term monitoring of forests – one of Earth’s most important natural resources.

The EQM is fully integrated. In parallel, the various EQM campaigns at subsystem level together with the progress made on their associated CDRs have significantly increased the confidence in the Instrument design. However, the situation remains less favourable regarding the delivery dates of the flight units. As a mitigation, the use of the PAS EQM in the instrument PFM campaign is being investigated. This would allow to start the instrument PFM campaign as planned. The PAS PFM would then be installed on the instrument at the end of the campaign and regression tests

would be conducted. The PAS thermal tests and the characterisation on the EQM were completed in early December 2020 and followed by successful EMC tests.

The current planning calls for a launch in August 2023.

The DesertSAR airborne campaign to be flown over Namibia has been postponed once to September 2021 due COVID-19. It is still very uncertain if the campaign will go through this year but a decision will be made in the next weeks. In the meantime, the MoA with NCRST has gone through all the ESA approvals and is ready for the signature of ESA's DG and the NCRST Chief Executive Officer. Once the MoA is in place, all the campaign permits can be processed.

The BelSAR-P campaign is part of a multiple instrument campaign for agriculture and forest applications over a forest site in Germany (Kermeter, National Park Eifel). The campaign includes SAR acquisitions at C-, L-, and P-band, airborne and terrestrial lidar scans and forest census data. A progress meeting was held on 22 March. Processed P- and L-band data was presented. C-band data is currently processed. A collaboration was agreed with Wageningen University who will complement the data with drone-based lidar flights. Due to the COVID situation and restricted access to the study site during the spring and summer the remaining field work (terrestrial lidar and UAV lidar), will be carried out in Autumn 2021.

The science team continues to participate in a monthly telecon with the NASA GEDI and NISAR teams and the JAXA MOLI and ALOS teams. The protocol for the CEOS Land Product Validation (LPV) biomass cal/val programme has been endorsed at the CEOS SIT meeting on 23-25 March 2021. Under the lead of ESA a community initiative proposal for the coordinated collection and funding of in-situ observation called GEO-TREES has been submitted and accepted by GEO.

6.1.3 FLEX

On 19 November 2015, ESA's Member States selected FLEX as the 8th Earth Explorer mission (also known as the 4th Opportunity Earth Explorer Mission of the EOEP), upon recommendation from the Earth Science Advisory Committee. The Fluorescence Explorer (FLEX) mission will map vegetation fluorescence to quantify photosynthetic activity.

The conversion of atmospheric carbon dioxide and sunlight into energy-rich carbohydrates through photosynthesis is one of the most fundamental processes on Earth – and one on which we all depend. Information from FLEX will improve our understanding of the way carbon moves between plants and the atmosphere and how photosynthesis affects the carbon and water cycles. In addition, information from FLEX will lead to better insight into plant health and stress. This is of particular relevance since the growing global population is placing increasing demands on the production of food and animal feed.

So far, it has not been possible to measure photosynthetic activity from space, but FLEX's novel fluorescence imaging spectrometer will observe this faint glow, which serves as an indicator of photosynthesis. The FLEX satellite will orbit in tandem with one of the Copernicus Sentinel-3 satellites, taking advantage of its optical and thermal sensors to provide an integrated package of measurements. Launch is currently planned for October 2024.

A FLEX - Sentinel-3 convoy flight concept meeting was recently held with representatives from EUMETSAT (S3 operator) and flight dynamics experts from ESOC and ESTEC. The FLEX project presented the results of the orbit control strategy analyses, demonstrating that the strategy is safe and that the required operations coordination is reduced to a minimum not disturbing or endangering the S3 operations. In the next step ESA and EUMETSAT will together present this convoy flight concept the European Commission.

The FLORIS instrument CDR was kicked-off mid-December 2020 and a first round of collocations has been held end March. The main topics are addressing the non-compliances in instrument performances to which dedicated meetings have been held in April 2021. The major non-compliance is the straylight performance after correction at L1. The presented performances are excluding delta contamination after Instrument delivery, because it is expected to be very low but still needs to be demonstrated. Under this assumption the FLORIS instrument is compliant in the O2B band and not compliant in the O2A. The non-compliance is due to Out-Of-Band spectral straylight from spectral channels beyond the observable spectrum (>780 nm) which is not corrected at L1. This is considered a pessimistic case and Out-Of-Band correction and contributions are being reviewed.

The non-compliances for the relative Spatial and Spectral radiometric accuracy in the LR channel were already known at I-PDR. The marginal non-compliance for the Relative Spatial Radiometric Accuracy in the HR channel is currently being assessed.

The main concern was related to instrument subsystem shock qualification. Following the VESTA test in January and the consolidation of subsystem input shock loads, the way ahead for the affected instrument subsystems has been defined. Important technical issues have been resolved and mechanical/shock testing has resumed and will be completed for all remaining units by May -2021. On the Telescope (MICOS, CH and TOPTEC, CZ) the problem with the application of anti-reflective coating and appearances of delamination has been solved.

The overall schedule is driven by Floris and its schedule is driven by EQM first and then by the PFM. The Slit Assembly, the Telescope and the Focal Plane Assembly are on the critical path to start and complete the instrument PFM integration.

The Instrument CDR completion has slipped to Q3/2021 due to delays in the OMR test campaign and closeout of subsystem CDRs.

Campaigns and Cal/Val

DEFLOX (JB Hyperspectral, DE):

> Through this activity four ground-based instruments (“FloxBoxes”) measuring radiation at a high spectral resolution were procured in 2017. The future calibration / validation strategy will rely on this type of measurements performed at different heights to bridge the spatial scales from 1 m2 to the size of a satellite footprint.

AtmoFLEX:

> This activity which is complementary to DEFLOX, addresses the need to perform long-term fluorescence measurements by means of the above-mentioned ground instruments (FloxBoxes) in combination with relevant

instrumentation for atmospheric characterisation at different test sites in Europe (Germany, Italy, France, Poland, Switzerland and Spain). The originally planned measurement period at different test sites is finished and instrument operations were concluded. The performed analyses document the changes in fluorescence over the period of more than 16 months in relation to changing vegetation and atmospheric conditions. The campaign also addresses questions related to the process of re-adsorption of fluorescence when measured at different heights above the canopy.

FLEXSense:

The commissioning phase of Sentinel-3B provided the opportunity for a dedicated campaign making use of reprogrammed OLCI bands to simulate the FLEX convoy mission concept. With Sentinel-3B launched in April 2018, the convoy phase campaign focused on the summer months and five regions in Europe, and with one site in the US. The data acquisition report was made available in Q2 2019. The data analyses are proceeding well including the analyses of the satellite, airborne data and ground-based measurements in a heuristic manner. All airborne data was processed to L2 and made available to the campaign consortium and the L2 team.

SF-TAPE (FU-Berlin, DE):

This activity is dedicated to a detailed exploitation of FLEX & Sentinel-3 tandem concept for fluorescence retrieval by means of utilizing S3 tandem data as well as FLOX-Box measurements in combination with radiative transfer modelling and collocated atmospheric data. The activity started during Q2 2020

6.1.4 FORUM

FORUM was selected on 23-25 September 2019 as Earth Explorer 9.
The Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission will provide new insight into the planet's radiation budget and how it is controlled, and therefore improve climate models. More than half of Earth's outgoing longwave energy is in the far-infrared part of the electromagnetic spectrum, which has not been measured. FORUM will fill this gap.

Thanks to new technical developments, the Far-infrared Outgoing Radiation Understanding and Monitoring (FORUM) mission would measure radiation emitted from Earth across the entire far-infrared part of the electromagnetic spectrum. Significantly, it measures in the 15–100 micron range, which has never been done from space before.

These observations are important because Earth emits infrared radiation to space, which is affected by water vapour and cirrus clouds, which, in turn, play key roles in Earth's temperature.

FORUM's benchmark measurements would improve our understanding of the greenhouse effect and, importantly, contribute to the accuracy of climate change assessments that form the basis for policy decisions.

Two parallel Phase A/B1 system and critical technologies studies by two industrial consortia are now close to their completion. Following the completion of the Phase B1 study activities the two consortia have progressed in the technological pre-development contracts which are close to their completion with the exception of the testing of the Interferometer Assemblies which are still on-going for both consortia. The objective remains to complete the activities before the release of the FORUM space segment proposal.

The FORUM Space Segment ITT for the phases B2, C/D and E1 is on-going. The bidding period for the FORUM Space Segment ITT has been extended to 18 May 2021. As a consequence, the FORUM Contract Proposal can only be presented at IPC in September with a knock on effect on the Kick Off of the next phases. The schedule of these phases will be consolidated as part of the bid and the following negotiation, but the current launch date is currently estimated in the second half of 2026.

6.1.5 Earth Explorer 10

The Phase A system studies are ongoing for the Earth Explorer 10 (EE-10) candidate mission, Harmony, with two parallel system studies. The mission definition is being consolidated at system, satellite and instrument level, and the technology pre-development activities are being defined.

6.1.6 Earth Explorer 11

Following the release of the Earth Explorer 11 Call for Mission Ideas on 25 May 2020, 15 valid proposals have been submitted on 4 December 2020.Evaluation of the proposals has been finalised in mid-April 2021. Scientific aspects have been assessed by the Peer-Review Panels whereas technical and programmatic aspects have been assessed by ESA experts in the field of mission analysis, RF and optical instruments, platform, technology readiness, development risks and costs. The evaluation reports are being prepared as input for the ACEO meeting, which is planned for 5-7 May, where ACEO will make their recommendation. The decision on the mission ideas proceeding to phase 0 will then be in the remit of PB-EO at its meeting on 10 June 2021. .

6.1.7 Aeolus Follow-on

Following the successful launch and in-orbit operation of the Aeolus mission, significant progress has been obtained in the assimilation and processing of the Aeolus wind measurements. Recent results have demonstrated the value of Aeolus and its robust and complementary contribution to Numerical Weather Predictions and the direct monitoring of atmospheric dynamics and circulation.

The EUMETSAT Council has expressed its interest for a future operational Doppler Wind Lidar mission and proposed to ESA to prepare for a joint preparatory roadmap for a potential future operational mission.

As such ESA started with drawing lessons learnt, from the Aeolus development and in-orbit operations highlighting the need for preparatory activities such as potential enhancements of the existing technologies used in the instrument and satellite optimisations aimed at resolving the issues encountered during the in-orbit operations with the goal of improving performances and maximising robustness and lifetime, whilst retaining the key Aeolus heritage as far as possible. These improvements are regarded to be mandatory in view of a potential operational mission and of minimising recurrent costs for an affordable multi-satellite programme. ESA will liaise with EUMETSAT to consolidate the mission requirements and programmatic framework in preparation for a potential Aeolus FO mission, which would become the scope of a dedicated operational meteorological programme.

Activities are addressing the development and improvement of the Aeolus technologies and performances. Two phase A2/B1studies are conducted in parallel.

The Aeolus Follow-On Instrument Consolidation Study Baseline Design Review has been kicked-off and is on-going. The first step relates to the high level trade-offs and internal and external reviewers has been involved bringing their experience and lessons learnt from Aeolus, ATLID and Merlin. The first step was concluded on 26 March with the recommendation to baseline a bi-static architecture, allowing an increase of the instrument robustness and reliability. Following this the baseline design and performance budget for the selected configuration will be detailed and presented as part of the documentation be released mid-May. Both laser transmitter developments with Leonardo and ILT/ADS-D have held first progress meeting which were mainly focused on review of the requirements, lessons learnt and the interface consolidation, in particular addressing the thermal and mechanical interfaces. Concerning the wind lidar detector, the requirement review is on-going and architectures trade-off are proceeding in view of the first review planned early May.

Two parallel System Accommodation Studies (Phase A2/B1) will kick-off in Q1 2022 and will last 18 months

A few elements are key to EUMETSAT MSs: a longer lifetime, a more robust instrument and a low cost. ESA intends to submit an Aeolus Follow-On Programme to the ESA Ministerial in 2022 (CMIN22), for a Follow-on programme with EUMETSAT (ESA would procure the first satellite, and EUMETSAT the recurrent ones). The earliest possible target launch date is Q4 2029.

6.1.8 Arctic Weather Satellite (AWS)

Approved at Space19+ (ESA's Council at Ministerial Level), this small satellite (~100 kg) is the prototype for a future constellation of small satellites carrying microwave sounder instruments. The AWS advanced sensors will provide information about humidity, precipitation and ice clouds in the atmosphere. This data offers meteorological institutes excellent opportunities to improve weather forecasts in Arctic and subarctic areas, and helps improve the quality of global forecasts.

EUMETSAT would operate this potential future operational constellation. This prototype will serve for one year as a demo for the future constellation.

The AWS contract between ESA and OHB Sweden was signed on 9 March 2021 in an online event. OHB Sweden has also subsequently signed contracts with Omnisys (Payload) and Thales Alenia Space (Ground Segment).

The Qualification and Acceptance Review of the AWS PFM is planned to start in December 2023 with the launch in Q1 2024 (depending on launch opportunities).

The activities at system level during the last months have concentrated on the AWS Constellation. A system analysis of different orbital planes has been performed to identify the orbital manoeuvre needs versus different MLTANs (Mean Local Time of Ascending Node). The design of the operations concept of the Constellation has also started. This system analysis is necessary to identify and design modifications that the different orbital planes could require from the system.

In addition, the link budget between the Space Segment and Ground Segment has been analysed for different scenarios.

6.1.9 TRUTHS

Also approved at the Space19+, TRUTHS will provide benchmark measurements that improve our ability to estimate the radiative imbalances underlying climate change. Reference datasets from TRUTHS will be used to calibrate other satellite sensors, such as those carried on the Copernicus missions and the emerging constellations of small satellites.

The Phase-A study with the Industrial team is continuing and the first milestone – the Mission Definition Review – has taken place in March 2021, with a successful outcome, pending actions to be completed for the close-out currently planned on 21 April 2021

The prime contractor (Airbus Defence and Space Ltd) has completed the negotiations with the main industrial partners and is progressing in launching the technology pre-development activities foreseen in the Phase A/B1 work program. In particular the first check point on the detector design has taken place successfully on 23 March 2021, with first experimental results presented showing promising performance of the specific anti-reflection coating which is key for achieving the requirements needed by the TRUTHS system.

The TRUTHS Mission Advisory group (MAG) is providing support for the evaluation of the key mission requirements and the work of the Industrial team in preparing the Mission definition Review (MDR). The TRUTHS MAG is composed of 12 MAG members, scientists from both TRUTHS programme participating and non-participating Member States, complemented with experts from CLARREO-PF/NASA, EUMETSAT and C3S.

The Steering Board with the Delegates of the TRUTHS Participating States has met on 30 March 2021, to report about the Industrial Study, in particular the outcome of the Mission Definition Review (MDR) and to present the first benchmark estimates of the potential costs of the implementation Phase of the Program (B2/C/D/E1). This exercise has been requested by the Delegates of the Participating States, to ensure timely start of the preparation of the TRUTHS Program implementation at CMIN22.

6.1.10 ALTIUS

ALTIUS (Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere) is a satellite mission proposed by the Belgian Institute for Space Aeronomy and currently under development by ESA. Its main objective is to monitor the distribution and evolution of stratospheric ozone in the Earth's atmosphere. The industrial consortium is led by QinetiQ Space, acting as mission prime. The satellite design is based on the PROBA small satellite bus. The payload, developed by OIP Sensor Systems, is an innovative UV, visible and NIR instrument.

The mission is scheduled for launch in 2024 from Kourou.

Technical progress on the ALTIUS project was made to start Phase C activities for all subsystems after the successful PDR held end 2020.

Following the increased non-compliance to straylight requirement identified at PDR due to the additional contributor of out of field near field straylight in the UV and VIS, a lot of effort was put in place to improve the L1 straylight correction addressing this contributor and assessing the impact on L2 performances. Considering the System Performance Simulator could not be updated in short term to support the assessment, quick Level 0 representative performance inputs were generated and used to develop a specific algorithm capable to correct the additional new contributor. Analyses demonstrated the algorithm was capable to remove efficiently this contributor except at one specific wavelength (351 nm). Preliminary impact at L2 was assessed and showed the ozone retrieval algorithm was still converging to the right solution. A Performance Key Point meeting was organised with all involved parties and concluded that there was no evidence that design change keeping same instrument topology would improve the in-field/near field out-of-field straylight performances and in view of the preliminary assessment of performances at L1 and L2, it was decided to proceed with the Instrument development. Detailed assessments of L1 straylight correction algorithm are still on going as well as investigations of minor Instrument design adaptations to keep improving the overall L1 compliance status to requirements.

The PDGS developments progress nominally towards a PDR in May 2021. Flight Dynamic System PDR took place in February 2021.

6.2 Future Sentinel missions (planned and potential)

In addition to meteorological satellites, the Copernicus missions, which form part of the Copernicus Space Component, will collect robust, long-term climate-relevant datasets. Most of the development activities have been impacted by the Covid-19 sanitary situation with schedule delays of few months.

6.2.1 Sentinels-4/-5

The Sentinel-4 and Sentinel-5 missions are dedicated to monitoring the composition of the atmosphere for GMES Atmosphere Services. Both missions will be carried on meteorological satellites operated by EUMETSAT. The Sentinel-4 and -5 missions will provide information on atmospheric variables in support of European policies.

Services will include the monitoring of air quality, stratospheric ozone and solar radiation, and climate monitoring.

6.2.1.1 Sentinel-4

Sentinel-4 is dedicated to air quality monitoring. To be carried on the geostationary Meteosat Third Generation satellites, the Sentinel-4 mission aims to provide continuous monitoring of the composition of the Earth's atmosphere at high temporal and spatial resolution and the data will be used to support monitoring and forecasting over Europe. It comprises an Ultraviolet Visible Near-infrared (UVN) spectrometer and data from EUMETSAT's thermal InfraRed Sounder (IRS), both embarked on the MTG-Sounder (MTG-S) satellite. After the MTG-S satellite is in orbit, the Sentinel-4 mission also includes data from EUMETSAT's Flexible Combined Imager (FCI) embarked on the MTG-Imager (MTG-I) satellite. The Sentinel-4 instrument data, jointly with other data from future meteorological missions, will cover the need for continuous monitoring of atmospheric composition and air quality over Europe with a revisit time of about one hour. The main data products will be O3 (Ozone), NO2 (Nitrogen dioxide), SO2 (Sulphur dioxide), HCHO (Formaldehyde), CHOCHO (Glyoxal) and the aerosol optical depth.

The Sentinel-4/UVN instrument is a high resolution spectrometer system operating with three designated bands in the solar reflectance spectrum, covering the ultraviolet (305-400 nm), visible (400-500 nm) and near-infrared (750-775 nm) bands. The central Sentinel-4/UVN instrument parameters are a spatial sampling of 8 km over Europe and a fast repeat cycle over Europe and North Africa (Sahara) of 60 minutes. The respective spectral resolution is 0.5 nm in the ultraviolet and visible bands, with the goal of 0.12 nm in near infra-red.

The PFM instrument AIT activities progressed in a satisfactory manner during the last months:

- The complete optics system alignment verification in vacuum was successfully completed at the end of January 2021 confirming that very stringent optical requirements were met.
- Since February 2021 the Airbus AIT team completed the integration and alignment of the optics system onto the hosting Optical Instrument Module (OIM) structure and completed the integration of the Near IR Front-End Electronic (FEE) unit, of the Front-End Support Electronic unit and of the UV-Vis FEE unit onto the OIM.

Current schedule/Deliverable (does not consider the impact of COVID-19):

The Sentinel-4A delivery to MTG is planned for February 2022.

The Sentinel-4B delivery to MTG is planned for Q3 2023

6.2.1.2 Sentinel-5

To be carried on the polar-orbiting MetOp Second Generation satellite, the Sentinel-5 mission comprises an Ultraviolet Visible Near-infrared Shortwave (UVNS)

spectrometer and data from EUMETSAT's IRS, the Visible Infrared Imager (VII) and the Multi-viewing Multi-channel Multi-polarization Imager (3MI).

Given the overall delays incurred on the project, it was decided, in agreement with MetOp-SG, to implement a revised model philosophy. In order to allow the spacecraft assembly and qualification tests to proceed as planned, we will deliver first an Intermediate Integration Model (IIM), which is fully flight representative in terms of mechanical, thermal and electrical interfaces. The IIM is based on the refurbishment of the instrument STM and is populated with mass dummies for the optical units. The instrument PFM can then be delivered and exchanged at a later point in time. The refurbishment of the STM into the IIM optical module (IOM) is completed and the unit successfully passed vibration tests. Electrical functional tests are ongoing with the engineering models of the electronic boxes. ESD tests are planned at the end of March. The assembly will finally be delivered together with the Instrument Control Subsystem (ICS) and Detector Support Electronics (DSE) Proto-Flight units (PFM). The schedule for the IIM is now driven by the timely availability and integration of the ICS and DSE PFMs and final thermal vacuum tests.

With the objective of further consolidating satellite instrument operations procedures, MetOp-SG industry has requested the Sentinel-5 project to integrate the IIM to the satellite Simulator-EFM prior to integration on the satellite PFM. A change request was issued to the Sentinel-5 Prime for the incorporation of this activity into the instrument baseline. These include procurement of some additional elements (harness, PEB table, etc.) and incorporation of AIT support to the SimEFM activities performed at satellite integrator facilities. The related contract change has been approved. The new harness is manufactured and undergoing testing.

The manufacturing of all the flight model (PFM, FM2 and FM3) structures is completed. The PFM structure assembly is fully completed and ready to re-start the integration and alignment of the first PFM telescope. The FM2 and FM3 flight structures are also available at Airbus.

All spectrometers and sub-systems in the Sentinel-5 instrument have completed their Critical Design Reviews (CDR). Each spectrometer was analysed together with their respective telescope optics. The performance of the first PFM spectrometer (UV1) and Telescope were in line with the predictions, in many cases also slightly better.

The major non-compliances are still directly coupled with the stray-light performance of the instrument at Level-0, affecting all spectral channels, but particularly the SWIR-3 band. An efficient stray-light correction is of paramount importance and has direct impacts on the level of compliance with radiometric instrument requirements (absolute, relative and effective radiometric requirements). The Sentinel-5 Stray-Light Working Group has significantly improved the stray-light modelling, correction by the L1bpp and analysis of the performance. Spectrally resolved stray-light performance after correction are now available to the Sentinel-5 project and have been assessed by the L2 prototype processor team. Stray-light coming from in-field and in-band stray-light sources are well understood and characterized. Their contributions can be corrected adequately by the L1bpp as this stray-light contribution is directly linked to a stimulus on the nominal detector area. Out-Of-Band (OOB) and Out-Of-Field (OOF) sources are more difficult to assess and more difficult to correct.

The Sentinel-5A delivery to MetOp-SG is planned for November 2022

6.2.2 Sentinel-6 (Jason-CS)

The pre-storage of Sentinel-6B is planned to start in June 2022. Sentinel-6B launch is currently planned for December 2025 (indicative date still to be consolidated).

6.2.3 Copernicus Expansion Missions (ex-HPCMs)

Data from the Copernicus Sentinels developed by ESA, feed into the Copernicus Services, which help address challenges such as urbanisation, food security, rising sea levels, diminishing polar ice, natural disasters and, of course, climate change.

Looking to the future, the following six Copernicus Expansion Missions (previously called High-Priority Candidate Missions - HPCMs) are being studied to address EU policy and gaps in Copernicus user needs, and to expand the current capabilities of the Copernicus space component.

The six projects are currently in phase B2/C/D/E1.

CHIME: Copernicus Hyperspectral Imaging Mission

The CHIME mission, which includes a constellation of two satellites, aims at augmenting the CSC with precise spectroscopic measurements to derive quantitative surface characteristics supporting the monitoring, implementation and improvement of a range of policies in the domain of raw materials, agriculture, soils, food security, biodiversity, environmental degradation and hazards, inland and coastal waters, snow, forestry and the urban environment.

The mission would complement Copernicus Sentinel-2 for applications such as land-cover mapping.

The CHIME Qualification Acceptance Review (QAR) is currently planned for Q3 2028.

CIMR: Copernicus Imaging Microwave Radiometer

The aim of the Copernicus Imaging Microwave Radiometer (CIMR) mission, which includes a constellation of two satellites, is to provide high-spatial resolution microwave imaging radiometry measurements and derived products with continuous global coverage (~95% daily, no gap at the poles) and sub-daily (6 hours average) revisit in the polar regions and adjacent seas, to address Copernicus user needs. The primary mission requirements are to acquire global observations to address Sea Ice Concentration (SIC) and Sea Surface Temperature (SST) with secondary requirements covering a very wide number of parameters related to COM Arctic Policy including: ice-type, sea-ice drift, thin sea-ice thickness, terrestrial snow extent, sea surface salinity, ice surface temperature, wind speed over the ocean, soil moisture, and vegetation indices. CIMR satellites will operate in synergy with MetOp-SG(B), providing collocated and contemporaneous measurements in the polar regions with MWI/ICI and SCA instruments.

CIMR will be operated by ESA and EUM will generate and deliver the global ocean L2 products

The CIMR QAR is currently planned for Q2 2028.

CO2M: Copernicus Anthropogenic Carbon Dioxide Monitoring

This mission, which includes a constellation of three satellites, aims to provide Copernicus with a CO2 monitoring and verification support capacity, capable of estimating anthropogenic CO2 emissions at country and megacity scales. This operational capacity shall allow evaluating the implementation and effectiveness of the CO2 emission reduction strategies proposed in the Paris Agreement. Such a system needs to provide accurate and consistent quantification of anthropogenic CO2 emissions and their trends. As part of the product portfolio and in support of the main mission objective, there will be also CH4, NO2, aerosol and solar-induced fluorescence of vegetation operationally retrieved at similarly high spatial resolution. Although this includes air quality relevant information, these products are not necessarily retrieved in near-real time.

CO2M will be operated by EUMETSAT

The CO2M QAR is currently planned for Q3 2025.

CRISTAL: Copernicus Polar Ice and Snow Topography Altimeter

The Copernicus polaR Ice and Snow Topography ALtimeter (CRISTAL) Mission, which includes a constellation of two satellites, shall provide enhanced retrieval of land ice sheet/glacier elevation, sea ice thickness and freeboard and ocean surface elevation, wave-height and wind speed by measurements implementing higher spatial resolution. The primary high level objectives are to monitor critical climate signals: ice sheet, ice cap melting and sea level, as well as to monitor variability of Arctic and Southern Ocean sea-ice and its snow loading to support Copernicus operational products and services concerning the polar regions. Other objectives are to support applications related to coastal and inland waters and contribute to the observation of ocean topography. CRISTAL will carry a multi-frequency radar altimeter and a microwave radiometer.

CRISTAL will be operated by ESA and EUM will generate and deliver the global ocean L1 and L2 products.

The CRISTAL QAR is currently planned for June 2027.

LSTM: Copernicus Land Surface Temperature Monitoring

Surface temperature is already being observed from space with thermal infrared (TIR) sensors, however at spatio-temporal resolutions insufficient for many applications and services, including agriculture. The LSTM mission, which includes a constellation of two satellites, will increase the spatial resolution of the TIR observations currently provided by Copernicus by a factor 400, bringing them to field scale. This mission shall be able to complement the current visible (VIS) and near-infrared (NIR) Copernicus observations with high spatio-temporal resolution TIR

observations over land and coastal regions in support of agriculture management services and possibly a range of additional services.

The LSTM QAR is currently planned for October 2028.

ROSE-L: L-band Synthetic Aperture Radar

As part of the Copernicus expansion, ESA has undertaken the development of the L-band Synthetic Aperture Radar (SAR) Mission, referred to as Radar Observing System for Europe (ROSE-L). This mission, which includes a constellation of two satellites, will acquire systematically and provide routinely data and information products for the Copernicus Marine, Land, Climate Change and Emergency services, as well as to the recently proposed Copernicus Land Motion service.

Its target applications are the measurement of surface deformation of vegetated terrain, soil moisture, land cover classification, crop type discrimination and its temporal analysis. Furthermore, the mission will monitor Polar ice sheets and ice caps, and the sea-ice conditions (i.e. type, drift, deformation, concentration, lead fraction), as well as contribute to the European maritime situational awareness. The envisioned acquisition of co-located ROSE-L and C-band Sentinel-1 SAR data within a short time interval, providing quasi multi-frequency imagery, will improve the classification of sea-ice types and the estimation of sea-ice drift, respectively. The ROSE-L mission will provide repeat-pass SAR interferometry (InSAR) capability for each ROSE-L satellite.

The ROSE-L QAR is currently planned for Q1 2028.

6.3 ESA Climate Change Initiative (CCI)

6.3.1 Background

Combined satellite and *in situ* data archives can be used to produce data products for climate monitoring, modelling and prediction. To this end, the ESA Climate Change Initiative (CCI) was launched in 2009. The CCI has been created to address the GCOS Essential Climate Variable (ECV) requirements for satellite datasets and derived products. Its principal objective is "*to realize the full potential of the long-term global Earth Observation archives that ESA together with its Member states have established over the last thirty years, as a significant and timely contribution to the ECV databases required by the UNFCCC*". The CCI focuses on the exploitation of data records primarily, but not exclusively, from past ESA satellite missions, for the benefit of climate monitoring and climate research. It complements existing efforts in Europe (e.g. led by EUMETSAT through the CM SAF) and internationally which focus on datasets characterizing meteorological aspects of the climate system.

6.3.2 CCI Phase 1

A competitive tender for proposals to generate climate-quality products addressing a first set of ECVs was released by ESA in the last quarter of 2009. As part of CCI phase 1, between August and December 2010, ten *ECV_cci* projects were launched. In addition to the ten *ECV_cci* teams, a CCI Climate Modelling User Group (CMUG) consisting of major European climate modelling centres was set up. At all stages of the program, its task was to provide a climate modelling perspective on the CCI, and

to test datasets generated in the CCI within their models. CMUG also aims to provide an interface between the CCI and the international climate modelling community. Finally, a CCI project on sea ice was launched in January 2012, together with two other projects dedicated to ice sheets and soil moisture, though funded under a different scheme. All CCI projects have reached the end of Phase 1 of the programme and generated ECV data products. The CMUG project Phase 1 was also completed by its deadline at the end of March 2014. In 2014 the *Ice_Sheets_cci* was split into two parallel contractual activities, covering respectively the Greenland and the Antarctic Ice Sheets.

6.3.3 CCI Phase 2

The last project to complete Phase 1 was the *Ice_Sheets_cci* at the end of March 2015. The kick-off meeting for Phase 2 of its two parts were held at the end of April 2015.

As the ECV products matured, the focus of project teams expanded from the specifications of the data sets to looking at how the data can be used, both across the CCI programme and in broader climate and environmental research questions.

The CCI project teams continued to make scientific publications in high impact scientific journals. The projects have also had time to promote their data sets more widely within their research communities. This means that some products have been downloaded extensively. There are variations between the projects depending on the product maturity, competition from other products, size of the research community, and how international it is but all are seeing a sea increase in users of their data.

6.3.4 Current status

The implementation of the CCI programme continues nominally:

- The planned procurements for CCI+ phase 2 are currently following the ESA approval process.
- In the scope of the CCI / Copernicus Climate Change Service (C3S) collaboration, 16 ECVs that have been transferred from ESA CCI to the ECMWF-lead C3S.
- Following the successful selection of ESA’s proposal to host the WCRP’s Coupled Model Intercomparison Project International Project Office (CMIP-IPO) at ESA-ECSAT (Harwell, UK), the working arrangement between ESA and WMO have been signed. The implementation of the CMIP-IPO has started.
- The forum ‘Remote Sensing of Tipping Points in the Climate System’ was held online 26-29 January 2021 in partnership with the Future Earth AIMES project and hosted by the International Space Science Institute (ISSI). It brought modellers and the remote-sensing community together to discuss how Earth observation can contribute to our understanding of tipping elements in the climate system and help with early warning of change. A pre-submission enquiry has been sent to Nature Climate Change.
- The European Space Policy Institute (ESPI) has started to undertake a public policy analysis of climate strategies to explore how satellite-derived CDRs - including those developed and generated by the ESA Climate Change Initiative (CCI) programme - are used for effective decision-making and implementation

on a national (ESA Member State) and EU level to shape positive change for a sustainable future both in the public and private sector.

6.3.5 Scientific highlights

The Antarctica Ice Sheets cci project published a survey of global ice loss that identifies an accelerating rate at which ice is disappearing (figure 12). *(Slater et al; https://doi.org/10.5194/tc-15-233-2021).*

The IMBIE project completed an updated assessment of Antarctic and Greenland ice sheet mass balance, bringing the previous records in line and updating them to extend through 2020. This update was requested by IPCC, and will feature in the Cryosphere and Sea Level chapters of AR6.

Glaciers_cci: A study reveals an upward trend in the number of lakes and associated local flood hazards and impacts on sea-level rise on the global scale. *(How et al; https://doi.org/10.1038/s41598021-83509-1)*.

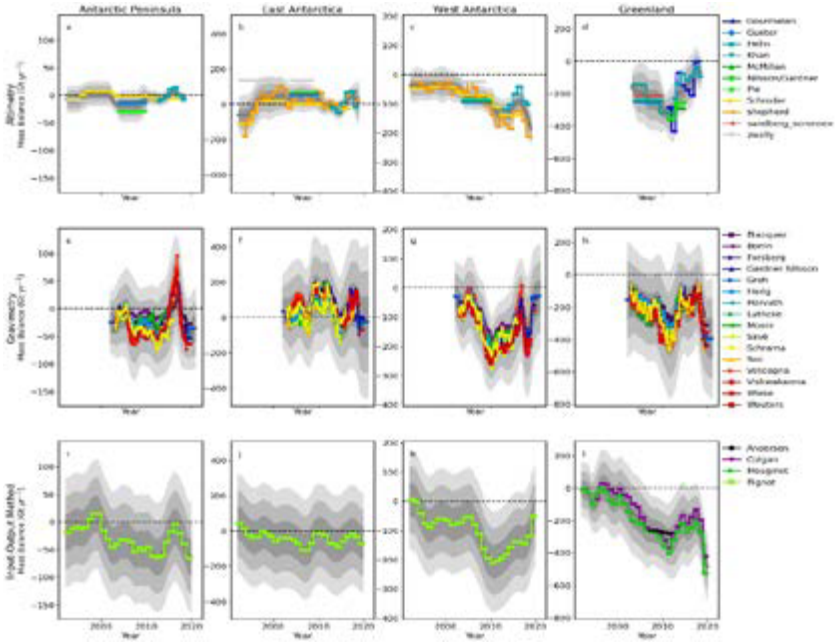

Figure 12: *IMBIE ice sheet mass balance estimates for the updated IPCC assessment for AR6.*

Sea Level_cci: Coastal communities are experiencing sea level rise four times worse than global water rise, according to a new study which estimates relative sea level rise and coastal flood exposure *(Nicholls et al; https://doi.org/10.1038/s41558-021-00993-z).*

Biomass_cci: Global maps for 2010, 2017 and 2018 at 1 ha have been released and brings the possibility of change mapping closer to reality.

CCI research fellow, Iestyn Woolway published a study in the journal Nature on Lake heatwaves under a changing climate *(Woolway et al; https://doi.org/10.1038/s41586-020-03119-1).*

Cholera prediction tool: developed by the ESA Climate Office, which incorporates many CCI datasets has generated from the UN Office for the Coordination of Humanitarian Affairs has shown interest in developing an anticipatory action framework for cholera in collaboration with WHO and other UN agencies. (Campbell et al; sea level subsidence https://doi.org/10.3390/ijerph17249378).

WMO Statement of the Climate 2020: The EUMETSAT OSI SAF (with R&D input from ESA CCI) sea ice extent data contributed to the WMO Statement of the Climate 2020 in March 2021. *Sea level_cci* data are also cited.
https://public.wmo.int/en/our-mandate/climate/wmo-statement-state-of-global-climate

Greenland_cci: Data have been included in the “QGreenland” QGIS data collection, which aims to improve access to a wide range of EO and in-situ data for scientists and advanced stakeholder, see http://qgreenland.org/ .